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A STUDY FOR CONFLAGRATION ANALYSIS: SYSTEM II(U)
INTERNATIONAL ASSOCIATION OF FIRE CHIEFS INC
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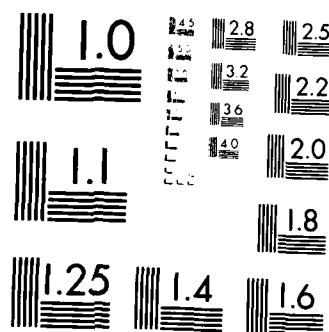
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A STUDY
for
CONFLAGRATION ANALYSIS: SYSTEM II

Final Report

for

Federal Emergency Management Agency, Washington, D.C. 20472

FEMA Award Number EMW-C-0743

FEMA Work Unit Number 6141A

April 1985



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by

Harry Hickey

for

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20 ABSTRACT (Continue on reverse side if necessary and identify by block number) This study examines the current relevance of the Gage-Babcock system for local assessment of conflagration potential of urban areas. Concerned with validation of the block assessment program, the study points to a need for an analytic approach for prediction of mass fire spread when wartime causal factors are not responsible for ignition.		
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The report contains a revised block rating methodology that applies new treatments to the following factors:

1. The fuel load and fire severity in compartments;
2. Perimeter building wall construction; and
3. Roof coverings and roof construction.

The study also assesses the need to develop additional methodologies relating to fire spread between urban blocks.

A variety of urban fire spread case studies are included. The findings of the project are reported in the following documents:

1. A Study Document for Conflagration Analysis: System II'
2. A Local Assessment Guide for Conflagration Analysis: System II
3. Conflagration Analysis System II - Bibliography.

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ABSTRACT

In 1982, a study was initiated by the International Association of Fire Chiefs to determine the current relevance of the Gage-Babcock system for local assessment of the conflagration potential of urban areas. This assessment tool has been used as one evaluation method for determining potential for a devastating fire under wartime conditions in individual urban structural blocks. The assessment process assumes that an ignition takes place in any urban block where 50 percent of the land is built upon. A numerical block rating is determined through a quantitative process to establish a relative measure of conflagration potential given a set of assumptions clearly defined in the assessment methodology.

This new study is concerned with the validation of the block assessment program, and the necessity to develop an alternative approach to block risk analysis that may be used to predict the relative potential for mass fire spread after ignition from a source not connected with wartime causal factors.

An extensive literature search concerning both the concept and the methodology of the Gage-Babcock block rating analysis strongly suggests the need for modifying the numerical parameters associated with some of the functional analysis items.

A revised block rating methodology has been constructed based on the literature search findings. In contrast to the original block rating analysis, the revised block rating method gives new treatments to the following analysis factors:

1. The fuel load and fire severity in compartments;
2. Perimeter building wall construction; and
3. Roof coverings and roof construction.

However, the basic concepts of analysis used in the original block rating method appear basically sound for the purpose of assessing mass fire potential in urban blocks under the condition of a well developed structural fire.

An initial validation study of both the original block rating methodology and the revised block rating methodology was conducted during the summer and fall of 1982. Three separate studies were conducted using senior fire protection engineering students from the University of Maryland; fire officers from the Alexandria, Virginia, Fire Department and selected emergency management personnel from the Washington, D.C., Council of Governments area.

On the basis of the validation program, a number of significant refinements and component changes were made to the local assessment method for measuring mass fire spread potential in urban blocks. The validation program also suggested the need for expanding the study methodology to include a local assessment method for measuring fire spread potential between urban blocks. A second study phase was initiated in 1983 to accomplish this task.

A new guide was prepared, focusing on the probability of fire spread between urban blocks, following a new literature search on the measurable effects of fire spread between structures separated by a defined gap or space interval. The developed methodology builds on the quantitative analysis developed for the mass fire spread potential in urban blocks. A probability factor of fire spread measure between blocks is introduced into the methodology based on street gap or open area width, building height ratios, exterior wall surface treatment, and selected wind factors.

In late 1983 and early 1984, a new round of studies was conducted to validate both phases of the described study. These studies were conducted in Atlantic City, New Jersey; Louisville, Kentucky; and Syracuse, New York. A

complete analysis of the validation study process is presented in the primary study document. However, the following conclusions are important to the study process findings.

The block rating concept for quantifying the mass fire spread potential in urban blocks and fire spread potential between urban blocks provides an important urban administration tool for the following applications:

1. Determining the relative fire spread potential within selected urban block configurations;
2. Determining the relative probability of fire spread between urban blocks given a well developed fire in a single block;
3. Determining different quantitative indicators for fire demand zone (FDZ) identification; FDZ identification can be used to -
 - a. Assess equipment and personnel resource requirements,
 - b. Designate adaptive response criteria, and
 - c. Establish public awareness on the potential threat of fire development in urban block areas of a given city;
4. Determining the fire safety impact of urban renewal efforts through the assessment of "before" and "after" results of structural-occupancy changes;
5. Determining structural condition risk assessments as an alternative to the disbanded community structural gradings provided by the Insurance Services Office, and
6. Determining the relative structural risk potentials in a community on a quantitative base; this type of risk assessment appears to be especially useful for -

- a. Fire officer education and development at the National Fire Academy in the area of risk management and
- b. The integrated emergency management system (IEMS) approach to emergency preparedness for considering the evacuation requirements, communication needs, emergency direction and control, continuity of government, resource management, and law and order in the event of a conflagration.

The positive indicators listed above are tempered by an identified list of concerns pertaining to both phases of the stated study. These concerns appear as follows:

- 1. Both methodologies are very time consuming and are labor intensive because of the large number of calculations that must be completed for a single block rating analysis of mass fire potential;
- 2. The method of computing fire spread between block areas is excessively complex in the present form for the intended purpose of a local assessment analysis;
- 3. The local assessment guide supplied to the validation cities does not provide sufficient depth and clarity for use by local governments without further instruction and assistance in specific applications
(Note: As indicated above (Item 6, page 3) there appears to be a strong feeling that this program should be incorporated into the Executive Series of course offerings at the National Fire Academy);
- 4. A computer program should be written to analyze field collected data and compute the numerical block rating or fire spread rating;

5. A number of fire officers, especially in fire prevention bureaus, would like to see an adjustment made to the methodology to account for buildings protected by automatic sprinkler systems, and

6. Fire officers involved in the validation study suggest that impact measures be developed for assessing the value of the responsible fire department and other local government agencies in halting a spreading fire between structural blocks.

It can be concluded that the general scope, methods, and objectives of the local assessment guide for determining mass fire spread potential in urban blocks and the probability of fire spread between blocks is sound and should be advanced to the fire service. One or more programs at the National Fire Academy appear to offer appropriate and acceptable methods for advancing this program to the fire service. The current documentation on the local assessment guides should be extended to include an impact analysis of automatic sprinkler protection and fire suppression capability in reducing the threat of mass fires and conflagration type fires in urban areas. When all of this is accomplished, the total program should be computerized and implemented into the integrated emergency management system supported by the Federal Emergency Management Agency.

The total study project is presented in three reports:

1. A Study Document for Conflagration Analysis: System II
2. A Local Assessment Guide for Conflagration Analysis: System II
3. Conflagration Analysis System II - Bibliography

These reports are available through the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. In addition, a notebook containing the field study data sheets is available at the International Association of Fire Chiefs.

mathematical formulations that depict the requirements for calculating numerical values associated with parameters in the conflagration model. An assessment of this material is discussed in the revised local assessment guide.

B. Measurement of Fire Severity

Coward reports (1975) on recent experiments demonstrating that the severity of a fire involving a compartment bears a relationship to the fire load, area of walls and ceiling and window area (1). Since these quantities vary from room to room, and from one building to another, fire severity must itself vary and must be regarded as a statistical parameter. The object of this work is to estimate the distribution of this parameter for one particular room use in one type of building, so that the level of risk associated with different levels of protection can be assessed. This information is essential to the assessment of fire containment in buildings and the ability of the structure to hold a developing fire to the modular level of origin.

The report builds a simulation method to combine the distribution of fire load, room dimensions and window areas. The likely severity of a fire involving a room is related to the room size and shape, window area, and fire load. This relationship is given in the following formula:

$$t_f = K \frac{L}{\sqrt{A_W A_T}} \quad \text{where:}$$

1. Coward, Sara K. A Simulation Method for Estimating the Distribution of Fire Severities in Office Rooms. Borehamwood: Fire Research Station, 1975. The original theoretical background is given in M. Law's "A Relationship Between Fire Grading in Building Design and Contents", Joint Fire Research Organization, Fire Research Note 877, Borehamwood, 1971.

SECTION IV

Analytic Approaches to Measuring Fire Development and Spread From Structures

A. Introduction

The Gage-Babcock model for conflagration potential determination is based on an analytic methodology for determining numerical block values. The block values are assessed on a relative scale to identify a given block's potential for mass fire development. A number of quantitative determinants relating the fire development in structures and the spread of fire between structures are used in the block analysis formula.

This section supplements an extensive evaluation of the literature on the section heading. The literature reviews concentrated on substantive issues and methodology statements. The concern of the literature search was to identify important and repeated variables and the possible need to reassess current methodology on the block rating analysis. The completed literature search is reported in a separate document.

The literature search identified several important quantitative measures that need to be carefully evaluated for each measurable item in the conflagration methodology. The specifics, in contrast to the generalities, of the material must be carefully documented and reported as part of the total study. This section discusses a range of identifiable measures associated with the stated problem.

The following analytical approaches to measuring fire development and fire spread in structures and from structures is important to any assessment for altering the current quantitative methodology documented in the Gage-Babcock conflagration model. In this document, specific attention is given to

SECTION III

Study Limitations

The scope and methods associated with this study are limited by the following considerations:

1. The stated comments on the validation studies represent the reflections of the 72 individuals participating in the respective exercises outlined in this document.
2. This study does not evaluate the potential impact of automatic sprinkler protection as a potential retardant to mass fire development in urban structural blocks.
3. This study does not evaluate the potential impact of organized fire department suppression forces as potential retardants to mass fire development in urban structural blocks and fire spread between urban structural blocks.
4. The findings and conclusions associated with this study are limited to cities in the population range from 150,000 to approximately 600,000 persons as reflected by the cities participating in the identified validation exercises.
5. This study is limited by the variables and operational constraints presented to the validation study participants. Suggested alternatives identified during study Phase II portion of the validation process have not been fully evaluated.

separate validation exercise relative to the perceived preparation of participants, the difficulties experienced by individuals and assessment groups, the length of time to complete the exercise, and the attitude of the participants towards the exercise.

- c) The specific nature of verbal questions also was recorded.
- d) Written comments provided by a few participants were carefully evaluated in the context of all other types of questions.
- e) Comments and observations from the verbal critique conducted after each exercise were carefully recorded and evaluated.

Step 10: On the basis of the process identified in the above steps, two sets of summary conditions were prepared. First, a set of conclusions was drawn concerning the local assessment program for mass fire potential and fire spread probability involving urban blocks. The potential value and general construct of the total program effort are evaluated in Section VII. Second, a set of conclusions is drawn that relates specifically to application of the local assessment guide and are reported in Section VII.

Future work relative to this project is the last item to be addressed. Concepts are presented for making the local assessment guide a useful tool for fire risk analysis in urban areas. Finally, thoughts are presented to implement the local assessment guide package in the most practical manner.

to determine a fire spread probability factor presented a number of difficulties.

The first problem centered around the basic formula relationship between the exposed block face and the exposing block face. It appears that the terminology relating to the relative hazard value required interpretation beyond that provided in the local assessment guide. The incremental values of twenty (20) feet for the facing walls of each block front caused problems where the computation lines did not match building separation lines. Finally, the sheer amount of "plugging and chugging" through the repetitive calculations caused much frustration.

There is little doubt that this study phase requires future work to simplify the method of assessment. This observation holds whether the calculations are accomplished by hand or by machine. The alternative process is outlined in Section VI.

Because of identified problems associated with the fire spread analysis, one of the validation cities did not complete the computational process; two of the cities completed the exercise with varying degrees of success.

Step 9: Results of the three validation exercises were evaluated according to the following objective criteria -

a) The deviation in block rating values between the participants for a given city are of importance. It should be noted that no direct intercity comparison was possible because the structural block configurations were different. However, standard deviations in the numerical rating between cities are identified for relative comparisons.

b) The principal investigator recorded observations during each

reported that the accomplished validation of the potential wind impact on fire spread is sketchy at best.

Step 8: The procedural step involved the validation of Study Phase II, applying the further revised block assessment methodology and the fire spread methodology to selected urban blocks in cities. The study process was hampered and slowed by initial inability to obtain commitments from cities to participate in the validation exercise. Reflections on this problem are enumerated in Section V.

The cities of Louisville, Kentucky; Atlantic City, New Jersey; and Syracuse, New York, did participate in a validation program.

Use and application of the local assessment guide for determining mass fire spread potential in urban blocks moved quite smoothly in all three cities. The consistency in determining block ratings improved over the initial study program. The participants, in aggregate, still expressed concerns regarding the time involved in completing a block rating. Development of a computer program to analyze the field data remained the number one recommendation.

The indicators are all positive for the continuation and refinement of the block rating analysis method for assessing mass fire potential in urban blocks. This item is considered an important tool for quantifying and defining risk levels associated with large scale fire potential in urban areas. It is generally considered that the work process should be shortened or machine calculations substituted for hand calculations.

The validation process for potential fire spread between blocks was less rewarding. The concept and need for this type of evaluation and measurement appeared to be well supported. The process of doing the actual computations

relationships involving fire spread by radiation factors. No single methodology was identified that specifically covered the concerns of this study. Abstracts of the literature reviewed are reported in a separate document.

Step 7: Based on the literature search identified in Step 6, a local assessment methodology for predicting fire spread between urban blocks has been developed and incorporated into the local assessment guide. The methodology builds on the concepts associated with mass fire spread and then proceeds to the final block rating(s) for determining the analytical probability of fire spread from a mass fire development in an urban block to an adjacent urban block. In other words, the model is structured around the fundamental concept that it is necessary to first determine block ratings for the two blocks under consideration; the fire spread probability is a direct function of the analytical association between these two blocks. A probability measure is then introduced based on the gap width between the structural block faces. A building height-area ratio is introduced as an intervening variable to the radiator and receiver which accounts for a directional concept within the fire spread phenomenon.

The basic fire spread methodology is subject to a further spread factor evaluation based on potential wind speed and direction. It appears that the most dominant factor in fire spread between structures is the support wind gives to fire intensity and associated radiation, conduction, and convection transfer elements. While almost everyone agrees on the variability of the problem, the quantitative measures necessary to label this problem are conspicuous by their absence. Therefore, the report methodology represents a logical analysis based on the quantitative data available. It needs to be

service personnel. Conclusions relating to this specific validation exercise are also reported in Section V. It is important to note that results of this exercise contrasted sharply with the student assessment evaluation. These participants considered the assessment process overly complex with specific reference to the wall evaluations. Most important, the program was criticized as being too time consuming and labor intensive. This group stated a view that field data should be analyzed on a computer. However, on a positive note, all of the participants agreed that the basic concept of the local assessment guide was valid and needed to be further developed and implemented into risk assessment programs for disaster planning. There was little support for the methodology to continue to consider fires initiated by a wartime action.

An important suggestion for improvement of the basic study focused on extending the assessment methodology to evaluate the potential or probability of fire spread from a mass fire in one block to an adjacent block.

Step 5: A second phase to the stated study was approved in 1983. Study Phase II extended the scope of the original study to incorporate a methodology for the local assessment of fire spread between urban blocks. This portion of the study includes a review of literature relevant to the topic area, the formulation of a local assessment guide, and the validation of this guide. The following steps continue to identify the methodology framework for accomplishing these three study elements.

Step 6: A literature search continued through 1983 and extended into early 1984 for the purpose of identifying concepts, principles, and analytical methods for the quantitative prediction of fire spread across an open space. The literature identified and reviewed presents several basic and consistent

Step 3: Findings from the literature search dictated a change in the numerical analysis associated with the following variable sets -

- a) Occupancy fuel loading conditions,
- b) Exterior wall evaluation,
- c) Height multiplier categories,
- d) Roof construction and roof cover, and
- e) Height distribution analysis.

The variable sets associated with floor construction, density multiplier, terrain multiplier, and the final block rating methodology remain as documented in the original study.

The quantitative values associated with the variable sets identified above are documented in the revised paper, Local Assessment Guide for Conflagration Analysis: System II.

Step 4: The revised local assessment guide was submitted to a two-phase validation process. The revised process for determination of mass fire spread potential in urban blocks was pilot tested with a group of 30 students enrolled in the fire protection engineering program at the University of Maryland. Each student rated a sample block by the original Gage-Babcock method and the revised method. Conclusions relating to this validation exercise are reported in Section V. However, it should be noted that the majority of evaluators thought that the exterior wall assessment process was oversimplified. The suggested revision incorporated looking at each structural wall face as an entity to itself. Other minor changes of note, including a working example, were incorporated into the revised guide.

In October 1982, a similar validation study was conducted in Alexandria, Virginia, using a total of seventeen (17) emergency management and fire

SECTION II

Study Methodology

This study is structured around several sequential methodology steps. The conceptual framework of these steps forms a basic foundation to the study. The following step functions serve to identify the study process and to further identify the scope, limits, and selected findings associated with the completed study:

Step 1: Early in 1982, a literature search was conducted to determine if a new or subsequent method of urban conflagration analysis has been developed since the 1965 study conducted by Gage-Babcock & Associates. No equal or substitute study was identified.

Step 2: A corresponding literature search was conducted during the first six months of 1982 on the qualitative and quantitative factors associated with fire development in structures. The literature search was especially sensitive to the component variables used in the Gage-Babcock document "A System for Local Assessment of the Conflagration Potential of Urban Areas". Data and information concerning the quantitative values associated with the variable set received careful consideration. A summary of findings associated with this literature search is reported in the Literature Abstracts for Study Phase I and Phase II.

At the completion of this literature search, it was concluded that no sound reason existed for altering the basic structure of the original Gage-Babcock local assessment methodology. However, it appeared that a number of quantitative changes were appropriate for elements of the assessment variables.

the study limitations, the analytic approaches to measuring the development and spread in structures, the local assessment guide, the validation process, study conclusions, and future developments. A separate document details the Local Assessment Guide for Conflagration Analysis: System II.

B. Study Mission

It is the mission of this study to develop and test a suitable method for the local assessment of mass fire potential in urban blocks and the probability of fire spread between urban blocks.

C. Study Objectives

Several study objectives follow from the basic study mission. The following specific objectives provide a framework for developing the study methodology:

Objective 1: Examine the Gage-Babcock "System For Local Assessment of the Conflagration Potential of Urban Areas" with respect to the study mission;

Objective 2: Modify the Gage-Babcock methodology as required or develop a new methodology if necessary to fulfill the study mission;

Objective 3: Construct a revised or replacement methodology from a current review of relevant literature published since 1965;

Objective 4: Validate the revised or replacement methodology using sample and existing block scenarios that are evaluated by emergency management and fire service personnel, and

Objective 5: Prepare a final local assessment guide for determining the conflagration potential of urban areas based on documented results of the validation process.

D. Study Modifications

The study is structured around the defined study mission and the developed objectives. Sections of this document detail the study methodology,

in buildings and between buildings dictates the need for both refining and expanding the basic analytical approach provided by the Gage-Babcock method to more accurately reflect a current understanding of fire growth conditions. In fact, the refinement process should be ongoing as a function of completed research and real world experience pertaining to urban fires that spread from the building of origin.

The concepts associated with this study develop from one central premise. The ignition scenario in a single urban structural block springs from a hazard-cause interface not associated with wartime or terrorist tactics. Further, the ignition is not controlled or extinguished by automatic fire suppression systems or manual fire suppression efforts. The fire is assumed to grow and spread as a function of occupancy characteristics and building construction to envelop the building of origin. At this point the analytical methodology responds to the basic question: "What is the risk of a mass fire developing that will spread beyond the building of origin to engulf the entire block?"

Block ratings developed by applying the local assessment procedure provide benchmarks for quantitatively predicting the relative potential for a mass fire.

Computed block ratings plotted on urban land-use maps are perceived to be useful in illustrating the relative mass fire potential in urban areas. Contiguous blocks that are assigned high block rating values chart a potential path for an urban conflagration. Additional measures discussed in this study illustrate the probability of fire spread between selected urban blocks.

SECTION I

Study Scope and Objectives

A. Background Statement

In the mid 1960s, Gage-Babcock & Associates developed "A System For Local Assessment of the Conflagration Potential of Urban Areas". This assessment tool has been used as one evaluation method for determining the potential for a devastating fire in urban structural blocks under wartime conditions. The literature on this topic indicates that the assessment process assumes an ignition may take place in any block where 50 percent of the land is built upon. A computed numerical block rating is designed to give a relative measure of conflagration potential given a set of assumptions clearly identified in the assessment methodology.

This study, conducted by the International Association of Fire Chiefs under direct sponsorship of the Federal Emergency Management Agency, was initiated to determine the relevance of the Gage-Babcock assessment method for urban structural mass fire spread after ignition from a source not connected with wartime causal factors. Therefore, a fundamental concept associated with this study is the appropriate measure of conflagration potential in urban areas based on fire ignition and spread phenomena associated with anticipated occurrences in the normal spectrum of urban activity. The initial work of this study concludes that the Gage-Babcock structural and methodological approach to the identified problem of conflagration analysis is basically sound.

However, an intensive examination of the literature in this field reveals that investigative work over the past twenty years on fire growth and spread

K has been found to vary from 0.7 to 1.5 when t_f is in minutes and the ratio $L/\sqrt{A_W A_T}$ is in kilograms/m².

t_f = measure of the severity of a fire involving the compartment (minutes)

L = the total fire load

A_W = the window area

A_T = the sum of the wall and ceiling areas, excluding A_W .

The simulated study is cross-correlated to the work of Berlin on measured fire severity (2). This comparison is made in Figure 1 taken from the Berlin study. This figure is important for examining the percentage of a room in a building with the corresponding fire resistance requirements.

Quintiere states that room fire-modeling provides a means for quantifying phenomena about fire behavior (3). The development of a room fire model is the process of defining the important phenomena, conceptualizing their interactions, specifying their functional relationships and assembling those components into a mathematical framework for solutions. Intensive experimental efforts have helped to identify and characterize the important phenomena occurring in room fires.

An important concept in this research work is the measured vertical temperature distribution in a room compared with the theoretical upper and lower space gas and surface temperature. This is presented in Figure 2 also from Berlin. Note how closely the computed values align with the predicted values. The analytical method can be accepted as a reasonable predictor of the fire event scenario in a room.

2. Berlin, Geoffrey N. "A Simulation Model of Fire Hazards" (Meeting Report). Boston: National Fire Protection Association, 1977.
3. Quintiere, James G. "An Overview of Fire Modeling". (Unpublished paper presented to the Society of Fire Protection Engineers' meeting in March, 1981.)

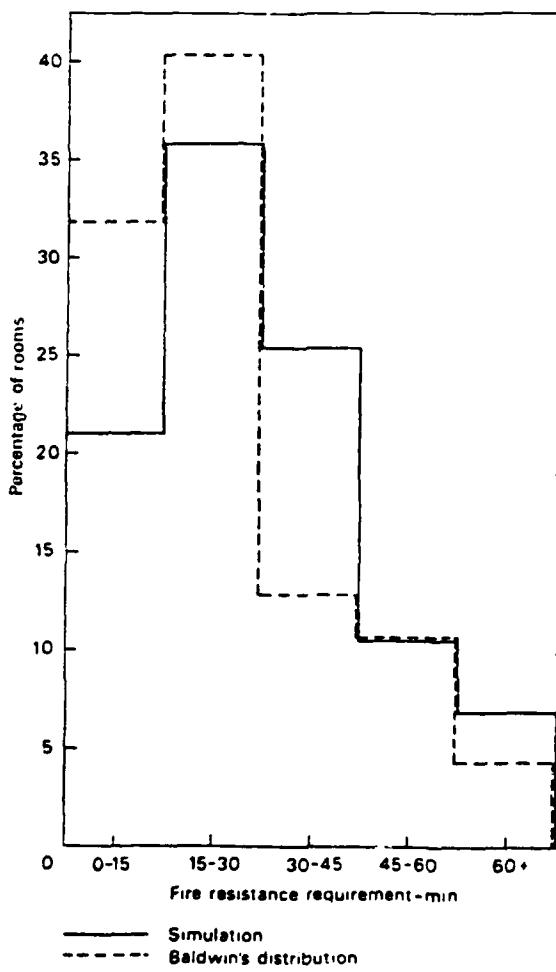


FIGURE 1

Comparison of the fire severity distribution obtained by simulation with the obtained by Baldwin from a survey of real rooms ($K = 1$)

Geoffrey Berlin, "A Simulation Model of Fire Hazards," (Meeting Report)
Boston (MA): National Fire Protection Association, 1977 - p. 11.

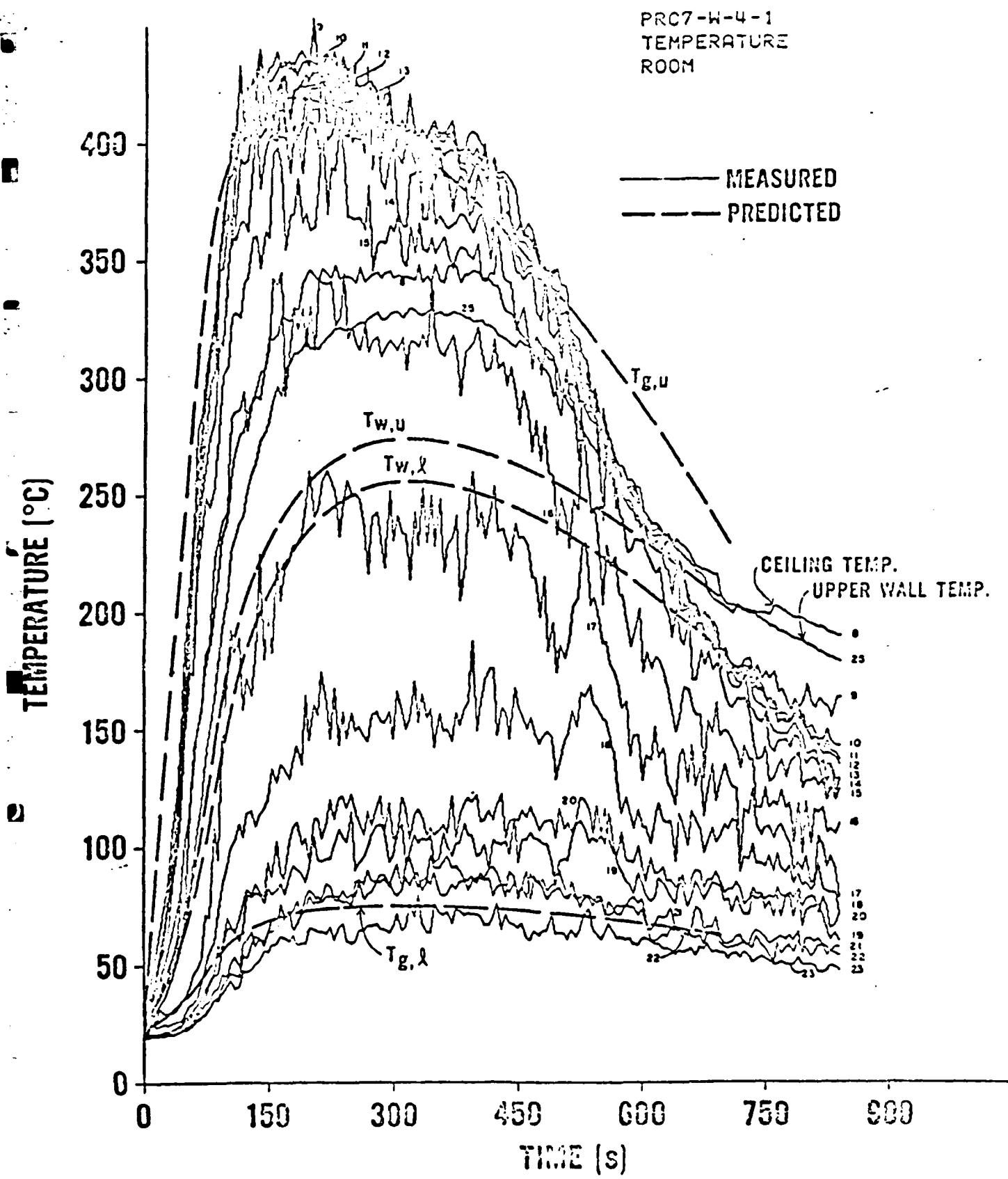


FIGURE 2

A measured vertical temperature distribution (gas: 9-23; surface: 8 and 25) in a room compared with theoretical upper ($T_{g,u}$ and $T_{w,u}$) and lower space gas and surface temperatures.

Geoffrey Berlin, "A Simulation Model of Fire Hazards," (Meeting Report)
Boston, (MA): National Fire Protection Association, 1977.

The temperature course of a fire in an enclosure, in practice, can be estimated as follows according to B. T. Lee (4):

1. Calculate the opening factor:

$$F_o = \frac{AVH}{A_r}$$

where F_o = opening factor

A = window area

H = window height

A_r = area of the inside surface of the enclosure

2. $t = WA_F (330 \cdot AVH)$

where t = duration of fire in hours

W = fuel load in Kg/m^2

A = window area in m^2

A_F = floor area in m^2

H = window height in m

3. The maximum temperature can be estimated from curves that relate F_o to t. See Fig. 2.2 in Lee, Reference 4, for example.

4. a. According to Lee, (Ref. 4), when "t" is less than 1 hour the rate is roughly 10 degrees C per minute;

- b. When "t" is equal to or greater than 1 hour, the rate of decay is roughly 7 degrees C per minute.

The concept of fire duration must be a key consideration in evaluating the framework of conflagration potential. Therefore, conceptually, a rapidly building fire is more hazardous than a slow fire. This is due partly to the higher rate of heat transfer into the structure during the faster (more severe) fire and partly to the increase of the rate of development of various physical and chemical processes (such as moisture transport, decomposition, and crystal transformation) with temperature. In addition, the larger temperature differences between outer and inner layers in the material will create larger thermal stresses in the structure when the fire is more severe. This, and the increased rate of development of the above-mentioned process,

4. Lee, B. T. "Modeling Individual and Multiple Building Fires". Menlo Park, (CA): Stanford Research Institute, 1972.

increase the chance of spalling, cracking, and failure, also accelerating those occurrences.

Figure 3, taken from Lee (5), shows an example of a relation between fire temperatures and fire duration for a specific fire. In practice, the time taken for a fire to grow to the flashover or fully developed state depends partly on the nature of the materials involved in the fire, and partly on the circumstances under which the fire grows, such as spacing of combustible materials, size and shape of room, size of the ignition source, the place where the fire started, and ventilation factors (6).

The probability of the occurrence of a fire with a long growth period, however, is greater for a room lined with a material which is rated as non-combustible (non-contributing) than for a room lined with a strongly contributing material. This concept is evidenced in the frequency of fire with flashover conditions. When in the expression for the required fire resistance the equivalent duration " t_e " is used instead of the anticipated actual fire duration " t ", and the relation for the required fire resistance become (7):

$$R = kt_e, \text{ where}$$

R = required fire resistance of the structural element under

consideration. The fire resistance of a structural element can

5. Ibid., p. 18
6. Ibid., p. 19
7. Ibid., p. 20

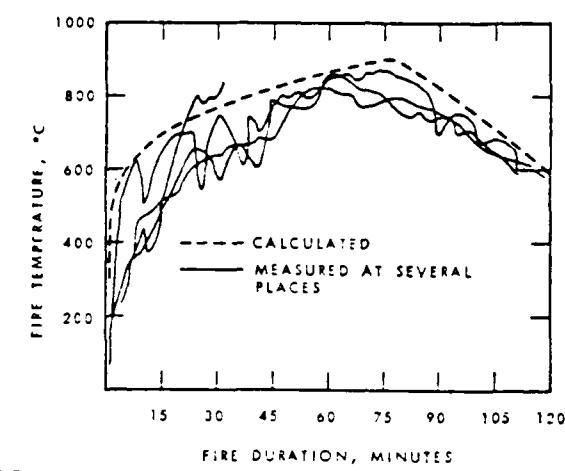


FIGURE 3
Estimated and Measured temperatures of an experimental fire.

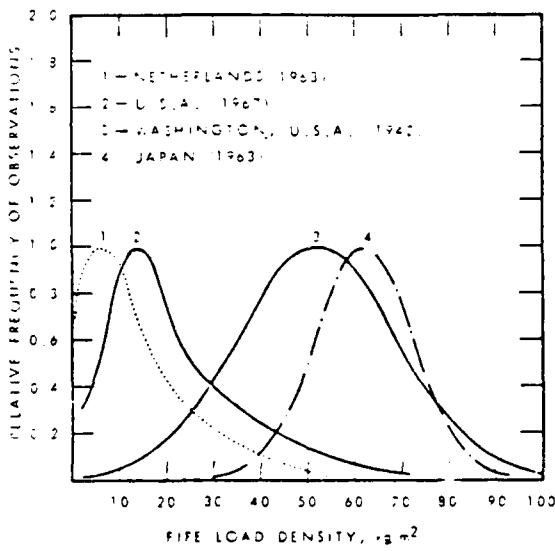


FIGURE 4
Results of survey of fire load densities in offices in various areas.

T. T. Lie Fire and Buildings. London: Applied Science Publishers, PP 18-20.

be determined experimentally by subjecting a specimen to heating according to the standard time temperature curve, or it can be computed.

t_e = the duration of heating according to the standard curve that gives an area under the curve that is equal to that under the anticipated fire temperature curve.

k = fire resistance safety factor.

It should be noted that the above equation expresses the relation between test results and practice. The more realistic the testing conditions, the smaller the appropriate value of the fire resistance safety factor and thus also the required fire resistance.

C. Fire Loading

Lee indicates that the fire load is a measure of the heat content of the combustible materials present in the room. The fire load is often defined as the heat content of the combustible materials per unit of floor area. Fire load can also be considered to be the total heat content of the combustible materials in an enclosure. In that case, the heat content per unit area is called the fire load density (8).

Some results of fire load surveys in offices in Japan, the Netherlands, and Washington, D.C., in the United States have been derived from study data obtained in the late 1960's. In this analysis it has been assumed that the fire load densities are normally distributed. The data is displayed in Figure 4 (9).

8. Ibid., p. 22
9. Ibid., p. 23

Odeen, writing in Lee's book, suggests that the fire load should be defined as the heat content of the combustible materials per unit of wall area instead of per unit of floor area. (10). This concept is expressed in the following equation:

$$t = (1/330) W' F_0 \text{, where:}$$

t = duration of fire in hours

W' = fuel load in Kg/m^2

F_0 = the wall opening factor ($\text{m}^{\frac{1}{2}}$)

$$F_0 = \frac{A \sqrt{H}}{A_r} \text{ (m}^{\frac{1}{2}}\text{) where:}$$

A = window area of the enclosure (m^2)

H = window height (m)

A_r = area of the inner surface of the wall bounding the enclosure (m^2).

In 1969, W. Halpaag worked out an important set of fuel loading factors for industrial structures in Germany (11). These values were cross-correlated to American buildings by the American Iron and Steel Institute. Figure 5, taken from this study, gives the relative factors as heat of combustion values. Using the conversion of 1 Mcal/Kg = 1800 BTU/lb., a relative

10. Ibid, p. 22

11. Kohlhammer, W. "Determination of the Fire Protection Class of Industrial Structures". Dormagen, Germany: Fire Protection, German Journal of Fire Departments, 1970, p.5.

Heats of Combustion - H_u (calculated values) of combustibles
in Meal, Kg at 20°C, 65% R.H. (DEV 50014)

COMBUSTIBLES	Heat of combustion in Meal/Kg	COMBUSTIBLES	Heat of combustion in Meal/Kg
<u>LIDS</u>			
Fuels		e) Miscellaneous	
Lignite Briquettes	5.0	Roofing paper with grit	4.0
Pine wood	4.0	Roofing paper without grit	5.0
Bituminous coal, coking coal		Hard rubber	2.0
Anthracite, sub-bituminous coal	8.5	Crude rubber, natural or synthetic	10.5
Anthracite coke	7.0	Linoleum	5.0
Wood, wood products, fibers, cellulose materials		Magnesium	6.5
Deciduous wood	4.0	Phosphorus	6.0
Coniferous wood	4.5	Sulphur	2.5
Excelsior building panels DIN 1101	1.5	Sugar	4.0
Wood sharing panels DIN 68761	4.0		
Porous wood fiber panels DIN 68750	3.5	f) Fertilizers	
Hardwood panels DIN 68750	4.0	Ammonium Sulphate-Potassium nitrate	0.5
Vegetable fibers (cotton, flax) cellulose based fibers	4.0	Urea	2.0
Animal fibers (wool, silk)	5.0	Bone Meal	4.5
Paper, cardboard, cellulose, excelsior, bamboo, grain, hay flour	4.0	Calcium Ammonium-Potassium nitrate	0.1
Synthetics		<u>LIQUIDS</u>	
Urea resins	5.0	Ethyl alcohol	3.5
Phenolic resins	6.0	Benzene, Benzol, Diesel Fuel, heavy oil	10.5
Polyacrylic acid - butyl ester	7.0	Gas oil	10.0
Polyamide	7.0	Glycerine	4.5
Polyethylene	10.5	Fuel Oil	10.5
Polycarbonate	7.0	Hexane (80%) and heptane	11.0
Polyester (without glass fibers)	6.5	Methyl alcohol	4.5
Polyester (with glass fibers)	4.5	Octane	11.0
Polyformaldehyde	4.0	Phenol	3.5
Polyisobutylene	11.0	Vegetable Oils	3.5
Polystyrol	9.5	Lubricating Oils	11.0
Polytetrafluorethylene	1.0	Toluol	3.5
Polyurethane	5.5	Xylol	10.0
Polyvinyl acetate	5.0	<u>GASES</u>	
Polyvinyl chloride (PVC) hard	5.0	Ethane	1.0
Polyvinyl propionate	6.0	Acetylene (13600 Kcal/Nm ³)	1.0
Waxes, Fats		Butane	1.0
Stearin	3.5	Carbon Monoxide (3020 Kcal/Nm ³)	1.0
Paraffin	11.0	Illuminating Gas (4000 Kcal/Nm ³)	1.0
Vegetable and Animal fats	9.5	Methane	1.0
		Propane	1.0
		Hydrogen (2580 Kcal/Nm ³)	1.0
		(1 Mcal/Kg = 1800 Btu lb)	

FIGURE 5

W. Kohlhammer, "Determination of the Fire Protection Class of Industrial Structures," Dormagen, Germany: Fire Protection, 1970 - p. 5

intensity table can be constructed for the purpose of examining fire intensity for given occupancies. Further, this information is useful for constructing a relative BTU chart based upon heights and areas. From this analysis it is further suggested that total BTUs can be calculated for building complexes.

Gamberg adds another dimension to this topic (12). Predicting the behavior of fire is a difficult task, one that must be undertaken using the most accurate criteria possible to have a reasonable chance of success in relating the theoretical to the practical. A study on fire load occupancy classification by Gamberg (1965) concludes that "modern methods and techniques of predicting the behavior and hazard of fire are not based on accurate criteria, and hence less accurate than is possible". The study indicates that the concept of fire loading is vastly overrated as a determinant of fire hazard and that the thinking in this area should be revised, possibly with a view towards qualitative as well as quantitative measurements of fire hazard. The qualitative suggestions revolve around the use of a professional review team to "adjust, where necessary", those occupancy classifications that appear more hazardous by inspection than is revealed by "broad categorization". This reflection appears important in light of the mechanism to examine and modify where necessary the conflagration block analysis method.

From a quantitative perspective, this study conducts a statistical validation of weighted relative fire loadings. This simply means that the study analysis shows that fire loading is not evenly distributed and

12. Gamberg, Alan. "A Study of the Validity of Occupancy Hazard Classifications in Sprinklered Occupancies and a Proposed Method for Occupancy Hazard Determination". (Unpublished report, University of Maryland, 1965).

therefore must be weighted to demonstrate the proportionality throughout the fire load range. The results are tabulated as relative fire loading indices using 10 pounds per square foot of combustible materials as the index of unity. The above concepts have been integrated to produce Table 1 on occupant fire loading in the local assessment guide.

D. Interior Finishes

Fang's research at the National Bureau of Standards reflects on an analytical approach to fire development in rooms based on the characteristic of the interior finish materials (13). It is reported that a variety of wall and ceiling panels in full-scale room corner tests have been exposed to a fire from a standard wood crib, simulating the environment produced by the burning of a single item of furniture, to evaluate their contribution to room fire growth. A total of twenty (20) room corner tests were performed using selected combinations of eight wood-base and gypsum-board-base interior finish materials on the walls and ceiling. Gas temperatures and velocities, surface temperatures, heat flux, smoke density, concentration of oxygen, carbon dioxide, and carbon monoxide were measured. Ignition times of newsprint, cotton fabric and plywood in the lower part of the room were recorded. The results of these full-scale tests were compared with laboratory tests on the ease of ignition, surface flame spread, heat release rate, and smoke generation on the same materials. The maximum upper room gas temperature has been found to agree with the ignition of such indicators as newsprint and

13. Fang, Jim B. Fire Buildup in a Room and the Role of Interior Finish Materials. Washington (DC): National Bureau of Standards, 1975.

plywood, and to represent a measure of fire hazard in terms of potential involvement of all combustible contents or room flashover. A temperature between 450 and 650 degrees C appears to mark the boundary between predicted limited and full involvement of room enclosures.

Two figures from this study appear to provide important information to the study of mass fire development; both figures referenced are attached. Figure 6, taken from this study, presents the tested relationship between materials, reported flame spread index and maximum upper room gas temperatures. The relationships may be important for examining the flashover condition that leads to rapid fire development. This information is supplemented with a set of regression equations set forth in Figure 7 (also from Fang) for expressing the correlation between laboratory and room corner tests.

E. Exposure Analysis

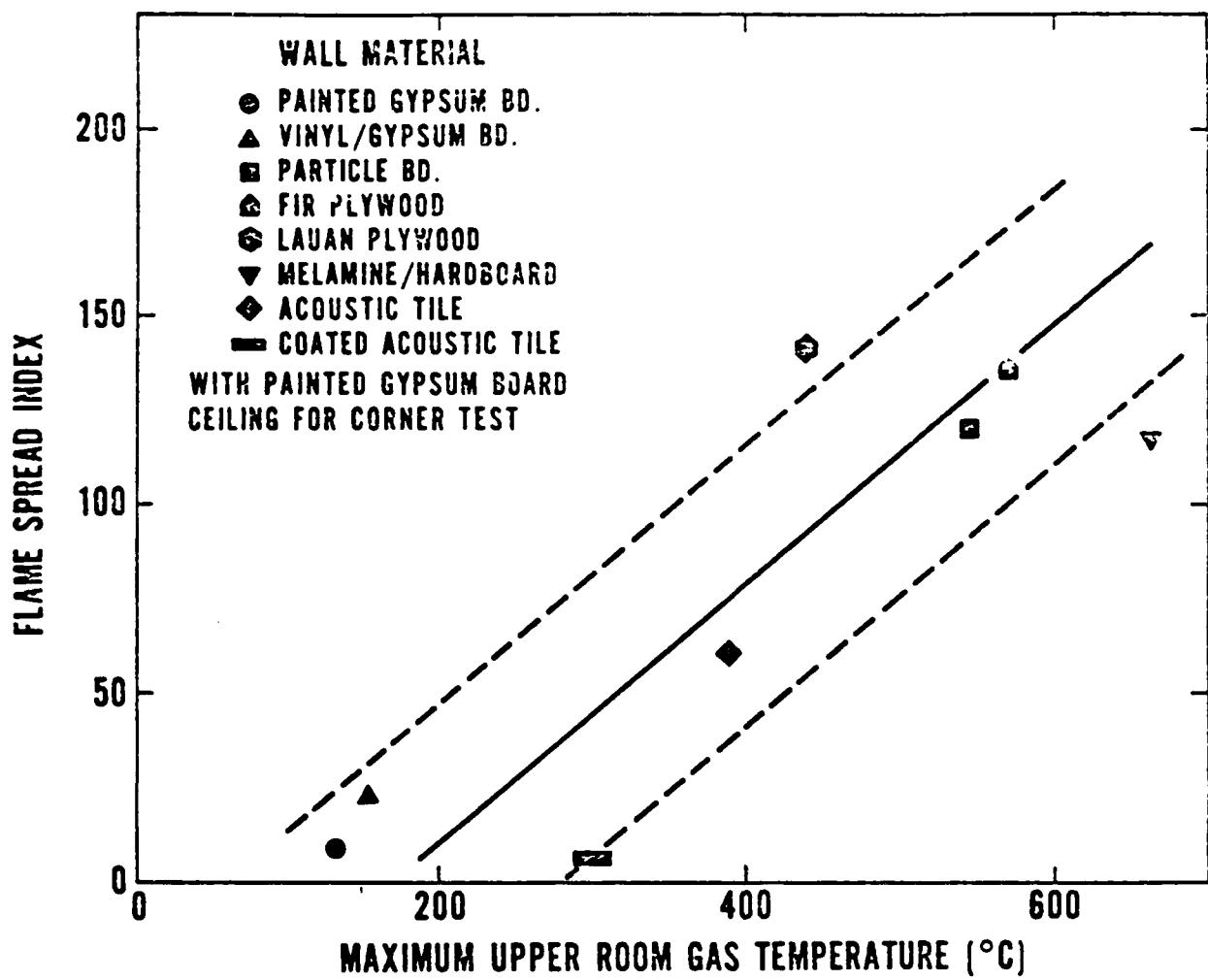
In the late 1960s, McGuire wrote extensively on the subject of fire and the spatial separation of buildings (14). This work is based on actual field studies of fires. The study is compressed into two tables that identify separation distances in feet as a function of -

Compartment width in feet,

Percent of window openings, and

Height of compartment.

14. McGuire, J. H. "Fire and the Spacial Separation of Buildings". Fire Technology, Vol. 1, No. 4, November 1965, FT-12.



Comparison of flame spread index measured by ASTM E162 Radiant Panel Test and the maximum upper room gas temperature by room corner test. Dashed lines represent limits of one residual standard deviation.

FIGURE 6

Jin B. Fang. Fire Buildup in a Room and the Role of Interior Finish Materials. Washington (DC): Center for Fire Research, National Bureau of Standards, 1975 - p. 32.

**Equations of the Regression Line from Correlations
of the Results of Laboratory-Scale and Full-Scale Tests**

Parameter	Laboratory Method	Regression ^a Line Equation	Residual Standard Deviation	Correlation Coefficient	Reference Figure No.
Ignitability	NBS Ease of Ignition [12]	$y = 0.61x + 97$	17 ^b	0.83	13
Flame Spread	ASTM E84 Tunnel	$y = 2.5x + 122$	96	0.89	14
	ASTM E162 Radiant Panel	$y = 2.9x + 178$	108	0.86	15
Heat Release Rate	NBS Calorimeter [15]	$y = 27.3x + 31$	89	0.89	16
	NBS Smoke Density Chamber	$y = 1.83x$	190	0.68	17
	Non-flaming Smoke	$y = 0.927x$	156	0.80	17

^aThe results of laboratory-scale tests were correlated against those by the room corner test. x denotes the figures of merit by laboratory tests, and y represents the appropriate measure results by the room corner test.

^bSamples which did not ignite in laboratory method are not included in obtaining correlation.

FIGURE 7

Jin B. Fang. Fire Buildup in a Room and the Role of Interior Finish Materials. Washington (DC): Center for Fire Research, National Bureau of Standards, 1975 - p. 33.

9. Rate of Heat Release, Ventilation Controlled Fires:

Determine the rate of heat release from ventilation controlled fires in the fully-developed stage. Multiply ϕ (step 3) by 202.

$$q_F = 202\phi \quad =$$

10. Upper Room Air Temperature:

Determine the upper room air temperature in the fire area.

- a. For the boundary enclosure of the fire area, determine the area of the enclosing walls. Area of walls =
- b. Find the area of the ceiling of the fire area Area of ceiling =
- c. Sum the areas of the walls (step 10a) and ceiling (step 10b) to determine A_T , the total surface area of the fire area. $A_T = (step\ 10a + 10b) =$
- d. Calculate the opening factor, F_o by dividing ϕ (step 3) by $27.5 \times A_T$ (step 10c). $F_o = \frac{\phi}{27.5\ A_T} =$
- e. Determine the fuel load, w , in the fire area. $w =$
- f. Determine the following factor: $\frac{.715\ A_f\ W}{\phi}$
see (step 3) for ϕ , (step 4) for A_f and (step 10e) for W . $\frac{.715\ A_f\ W}{\phi} =$
- g. Using Figure 2.1, determine the temperature using (step 10f) for one coordinate and (step 10d) to select the proper curve. $T =$
- h. Calculate the volume of the fire area. $V =$

11. Heat Stored by Upper Room Air:

Determine the amount of heat stored by the warm upper room air which must be released for cooling by:

- a. Subtract 400°F from the upper room air temperature (step 10g) $T - 400 =$
- b. Calculate: one percent of the room volume (step 10h). $.01V =$
- c. Determine the product of (step 11a) and (step 11b). $.01V(T-400) =$

12. Fire Flow:

Determine the fire flow by dividing the rate of heat release from the fire [(step 8) for fuel controlled fire, (step 9 plus step 11c for ventilation controlled fires)] q_F by 4680.

$$G = \frac{q_F}{4680} \quad =$$

5. Control Mechanism of Fire:

Determine if fire is fuel or ventilation controlled by dividing ϕ (step 3) by A_f (step 4). $\frac{\phi}{A_f} =$ _____

If $\frac{\phi}{A_f} \geq 3.22$ fire is fuel controlled; proceed to step 6.

If $\frac{\phi}{A_f} < 3.22$ fire is ventilation controlled; proceed directly to step 9.

6. Fuel Composition:

Determine if the combustible materials are mostly cellulosic and circle the appropriate answer.

Yes No

If no, proceed to step 7

If yes, proceed directly to step 8 and assume $\gamma = 1.0$

7. Fuel Composition Factor, γ :

- Determine the composition of the fuel in the fire area excluding cellulosics e.g. synthetics, flammable liquids, etc.
- Note the percentage of the total amount of combustibles which each type of fuel comprises (by weight) in the top row of the table, below.
- In the second row, note the heat of combustion, ΔH_c , for each type of fuel.

Combustible Materials											
Fuel Type	1	2	3	4	5	6	7	8	9	10	Total
% of total											X
Heat of Combustion, ΔH_c											X
(% of total) $\times (\Delta H_c)$											100

- Sum of the (% of total) $\times (\Delta H_c)$ for combustibles: _____
- Calculate the percentage of all combustible materials in the fire area which are cellulosic (by weight). % cellulosic = _____
- Multiply the percentage of cellulosics (step 7e) by 8000. $8000 \times \% \text{ of cellulosic} =$ _____
- Add the quantity in (line 7d) to (line 7f) and divide by 8000 to obtain γ

$$\gamma = \frac{(\text{step 7d}) + (\text{step 7f})}{8000} = _____$$

8. Rate of Heat Release, Fuel Controlled Fires:

Determine the rate of heat release from fuel controlled fires by multiplying the fuel surface area, A_f (step 4), by 610 and the fuel composition factor, γ (step 7f or assume 1.0)

$$q_f = 610 \times \gamma \times A_f = _____$$

Proceed to step 12

Calculation Technique Summarized

This section presents the resulting approach for a theoretically based calculation technique for determining the required amount of water for fire protection. The technique is based on the application of water to absorb the heat release rate from the fire and to cool the upper room air temperature. The technique is presented in steps for simplicity.

1. Fire Area:

Select the largest area of the building within a one hour fire-rated compartment Location of fire area: _____

2. Unprotected Openings:

For the boundary enclosure of the selected area, note the dimensions of all unprotected openings, e.g. doors, windows, etc., in feet. Complete the table below by calculating the area for each opening, the $A\sqrt{h}$ factor and summing the $A\sqrt{h}$ factors.

	1	2	3	4	5	6	7	8	9	10	Total
width (l)	X
height (h)											X
area (A)											X
$A\sqrt{h}$											

3. Ventilation Parameter, ϕ :

Determine the ventilation parameter, ϕ , by multiplying the total of all the $A\sqrt{h}$ factors obtained in (step 2) by 27.5.

$$\phi = \underline{\hspace{2cm}}$$

4. Fuel Surface Area, A_f :

Calculate the surface area of all combustibles in the fire area. Where possible, simplify the procedure by selecting "rectangular boxes" of combustibles and computing the area of the four sides and top. Use the table below for this process or any other appropriate method for calculating A_f the total of the areas for the sides and top is A_f .

Rectangular Boxes of Combustibles

	1	2	3	4	5	6	7	8	9	10	Total
length (l)											X
width (b)											X
height (h)											X
area-long sides ($2lh$)											
area-short sides ($2bh$)											
area-top (lb)											

$$A_f = 2lh + 2bh + lb = \underline{\hspace{2cm}}$$

FIGURE 15

James A. Milke (Unpublished Paper, University of Maryland, 1980)

rating methodology used in the current Gage-Babcock model and other related methods for determining required fire flow for structural buildings. The similarities and differences between methods appear to be significant in making any appropriate adjustments in the current block rating methodology.

H. Theoretical Method

Figure 15, on pages 45 through 47, offers a theoretical method for calculating risk that has been developed by Milke in an unpublished paper at the University of Maryland. The variables associated with this method are important as a comparison to the Gage-Babcock method. The concepts presented are useful in making appropriate adjustments in the current methodology.

NEEDED FIRE FLOW (300)

Block or complex boundary (by streets or other description): _____ Fire Flow number _____

Address and occupancy: _____

Fire area considered: Basement Yes _____ No _____. If yes, used? Yes _____ No _____

Construction Class _____ Construction Coefficient (F) _____

Ground floor area _____ Number of stories _____

Effective total area _____

From table (C_i) _____ gpm (310)

Occupancy combustibility class _____ Occupancy factor (O_i) _____ (320)

Factor for Exposure (X_i): None Chargeable

Side	Fire Bldg. Wall		Exposed Wall			(Check appropriate box)				(X_i) Table 330.A.	
	Blank	Other	Distance (feet)	(L)	(H)	(L) x (H)	$i, 3$	Openings*			
				Length (feet)	Height (Stories)			U	S	B	
Front											(a) i
Left											(b) i
Rear											(c) i
Right	-										(d) i

Factor for Communications (P_i): None Chargeable

Side	Construction		Passageway					(P_i) Table 330.B.	(Check appropriate boxes)			
	Non-Comb	Comb	O	E	U	SD	DD		L. (Ft.)	Table 330.B.		
Front										(a) i	(X_i) + (P i) = 1.00 (k)	
Left										(b) i	($)$ + () = (a)	
Rear										(c) i	($)$ + () = (b)	
Right										(d) i	($)$ + () = (c)	

* U = Unprotected (k) + (a) + (b) + (c) + (d) = (maximum 1.75) = $(X+P)_i$ = _____ (33)

S = Semi-protected (310) _____ x (320) _____ x (330) _____ = _____ (34)

B = Blank (310) _____ x (320) _____ x (330) _____ = _____ (34)

O = Open (310) _____ x (320) _____ x (330) _____ = _____ (34)

E = Enclosed (310) _____ x (320) _____ x (330) _____ = _____ (34)

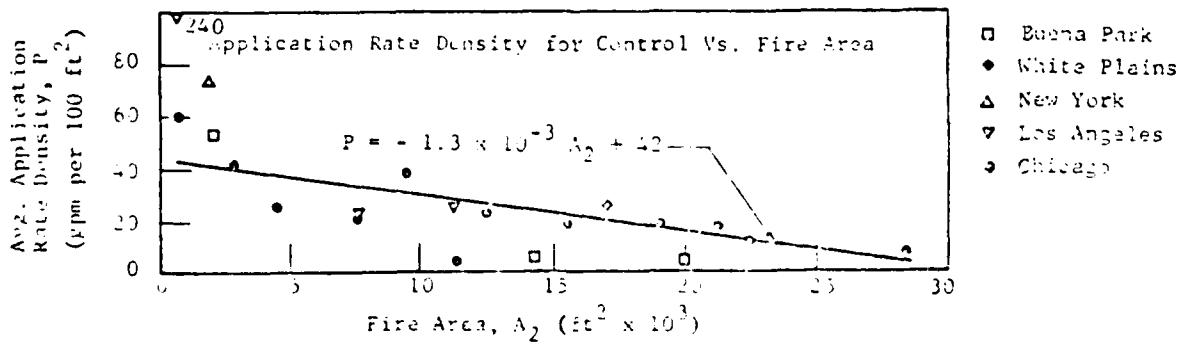
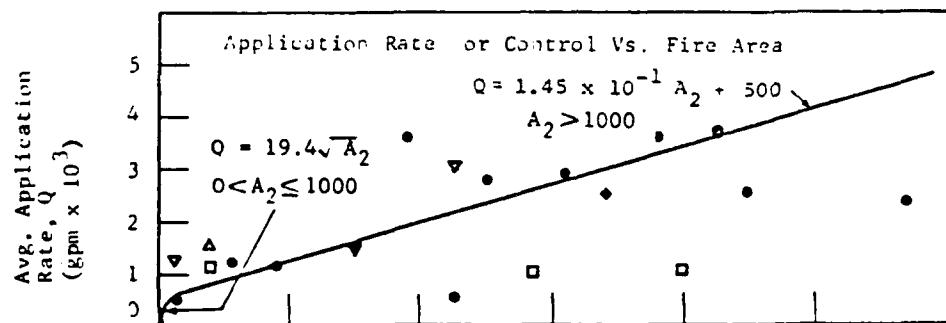
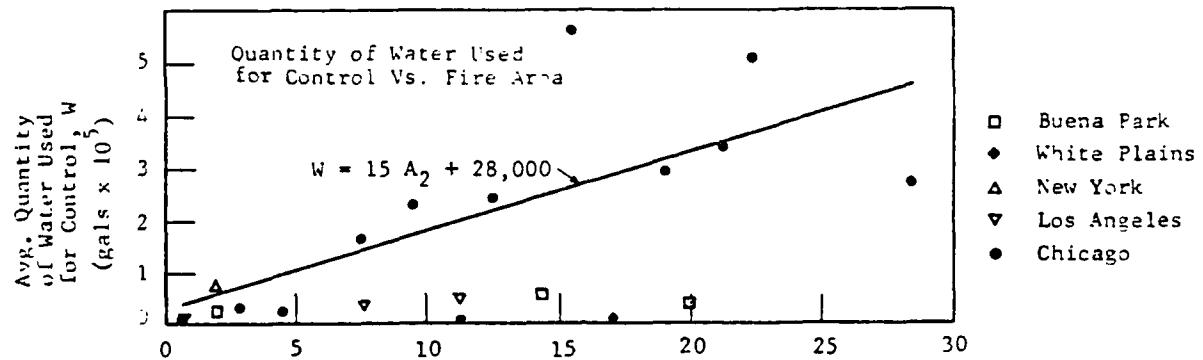
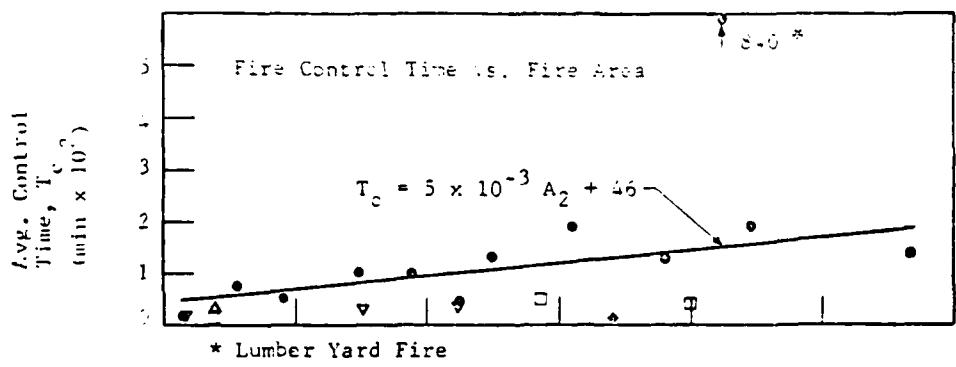
SD = Single Door (310) _____ x (320) _____ x (330) _____ = _____ gpm

DD = Double Doors (310) _____ x (320) _____ x (330) _____ = _____ gpm

Needed Fire Flow (NFF₁) = _____ gpm

FIGURE 14

Insurance Services Office, 1980



WATER APPLICATION AND TIME NEEDS
TO CONTROL NONRESIDENTIAL FIRES
(Average Within Each Class)

FIGURE 13
Frederick Salzberg. Fire Department Operations Analysis. Chicago (IL):
IIT Research Institute, 1970 - p. 13.

G. Risk Measurement and Water Supply

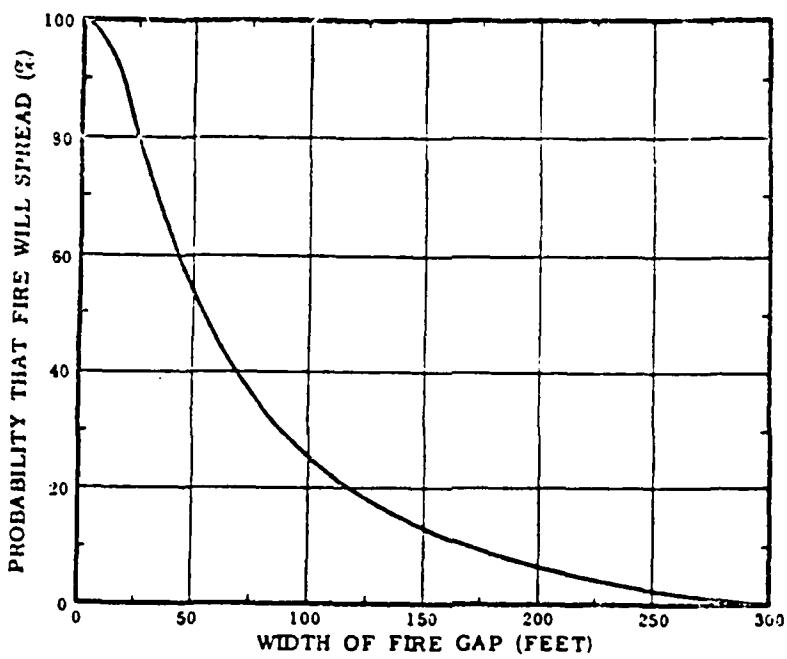
Salzberg (et al) considered water application as a function of time to control both residential and non-residential fires. The non-residential classification appears important to the information base associated with the conflagration study. It is important to note that the agreement of quantitative data appears to be good based on event analyses conducted in Buena Park, California; Chicago, Illinois; New York, New York; White Plains, New York; and Los Angeles, California (17).

This study documents four relevant linear equations for expressing the interrelationships between fire areas, time, and water application. Figure 13, taken from the report, depicts both the reported curve plots and the respective equations. Values obtained from this analysis can be compared to and contrasted with other study methods.

In 1980, the Insurance Services Office (ISO) significantly revised a major insurance company approach to determining needed water demand for fire in buildings. The current conceptual techniques consider most of the determining factors used in the Gage-Babcock conflagration model. It should be noted that the ISO Needed Fire Flow methodology gives special significance to the factors associated with exposure conditions and factors of communication between fire areas. Both of these factor areas are important to the measurement of conflagration potential.

Figure 14 is the basic procedural sheet for determining needed fire flow by the ISO method. This methodology can be cross-compared to both the block

17. Sulzberg, Frederic. Fire Department Operations Analysis. Chicago: Illinois Institute of Technology. (OCD Work Unit 25 22 F), 1970.



WIDTH OF GAP AND PROBABILITY OF FIRE SPREAD

FIGURE 12

Lester Eggleston . Fire Defense Systems Analysis. San Antonio (TX):
Southwest Research Institute, 1970 - p. 64

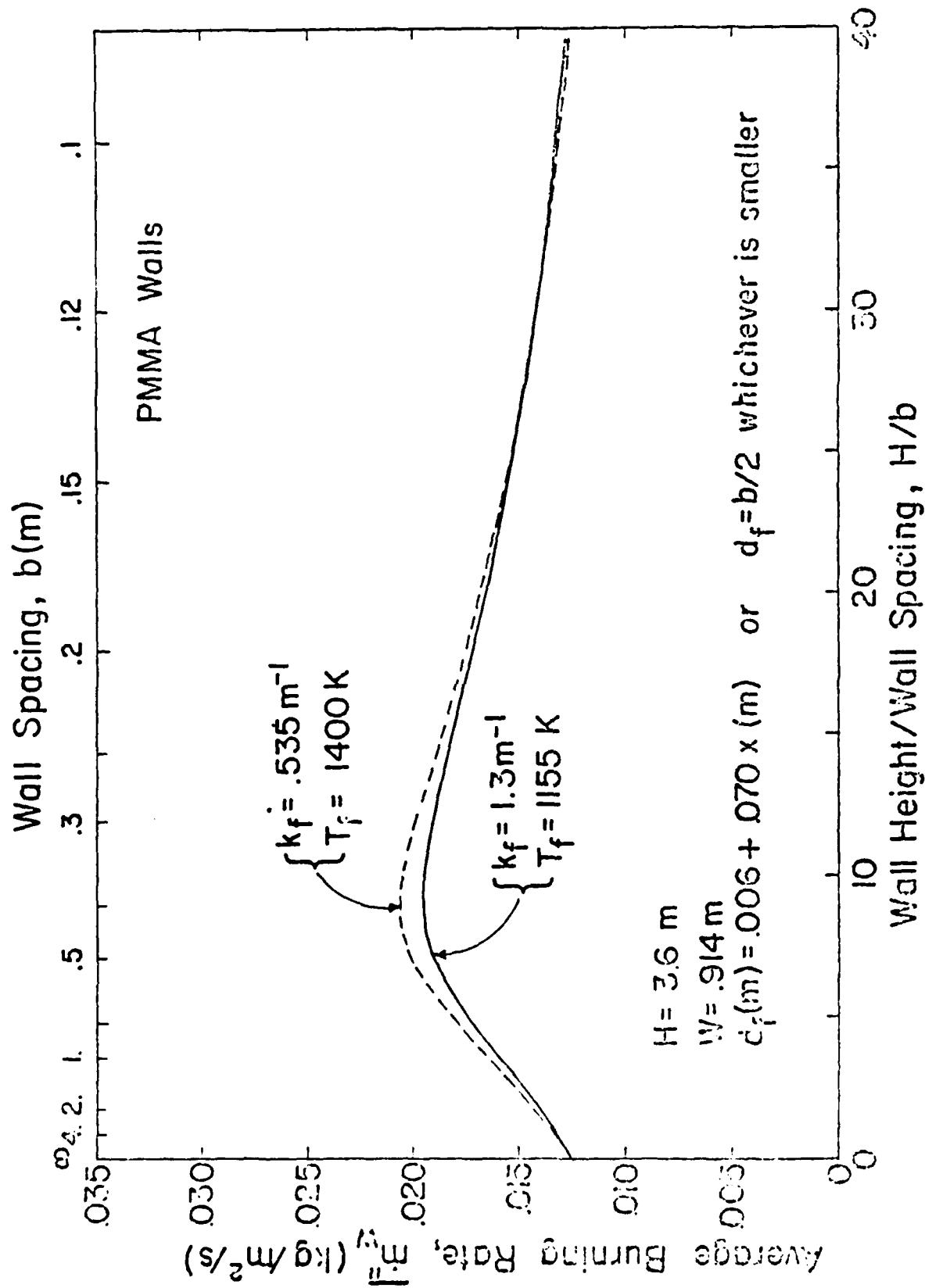
F. Firebreaks

Firebreaks are important for consideration in the mass fire and conflagration phenomena. Eggleston has researched this topic and the following numerical considerations come from his work. Again, the numerical values can be cross-correlated to exposure separation conditions and requirements.

Eggleston indicates that it is generally accepted that a conflagration or mass fire, once well established, is not apt to be halted until the fuel array is broken by some natural or human-built barrier (16). In a study of the potential effects of nuclear weapons, a firebreak probability chart was arranged (Figure 12).

From his own review of the literature, Eggleston notes that fire spread studies at Stanford, URS Research Corporation and the Illinois Institute of Technology Research Corporation have indicated that after the first 10 hours, the area in which 50 percent of the buildings were burning or burned would lie in the wind path at a distance in excess of five miles from the block of origin, without adequate firebreaks. Adequate firebreaks in this case are considered to be separations of 300 feet or more. Going back to the Gage-Babcock conflagration model, the firebreak distance effectiveness measures are based on block ratings of 70 or more.

16. Eggleston, Lester. Fire Defense Systems Analysis. (Application of Concepts to the San Jose Metropolitan Area - Final Report).



Prediction by the view-factor analysis of the effect of spacing on the burning rate of 3.6-m high, .914-m wide PMMA vertical parallel walls.

Francesco Tamanini, "Calculations and Experiments on the Turbulent Burning of Vertical Walls in Single and Parallel Configurations," Factory Mutual Research, 1979 - p. 41.

FIGURE 11

From the indicated charts and references it is demonstrated that the more noticeable changes in flame properties associated with increasing values of the vertical velocity in the free air stream with limits of 0 to 2 m/s are of the following:

1. 50.6 percent reduction in the volume with limits of 0 to 2 m/s of the flame front of the wall;
2. 54.3 percent reduction in the buoyancy force (N'_H) acting on the part of the flame in front of the wall;
3. 51.2 percent increase in volumetric release rate (q_{ch}'); and
4. 36.5 percent in the radiant heat flux at the top of the wall.

A possible maximum increase in burning rate, over the single wall case, on the order of 40 percent corresponding to a wall spacing about equal to 20 percent of the wall height can be concluded from analysis of this study. Confirmation of this estimate from the data obtained in this program is not fully conclusive and the development of a more complete analysis is probably in order.

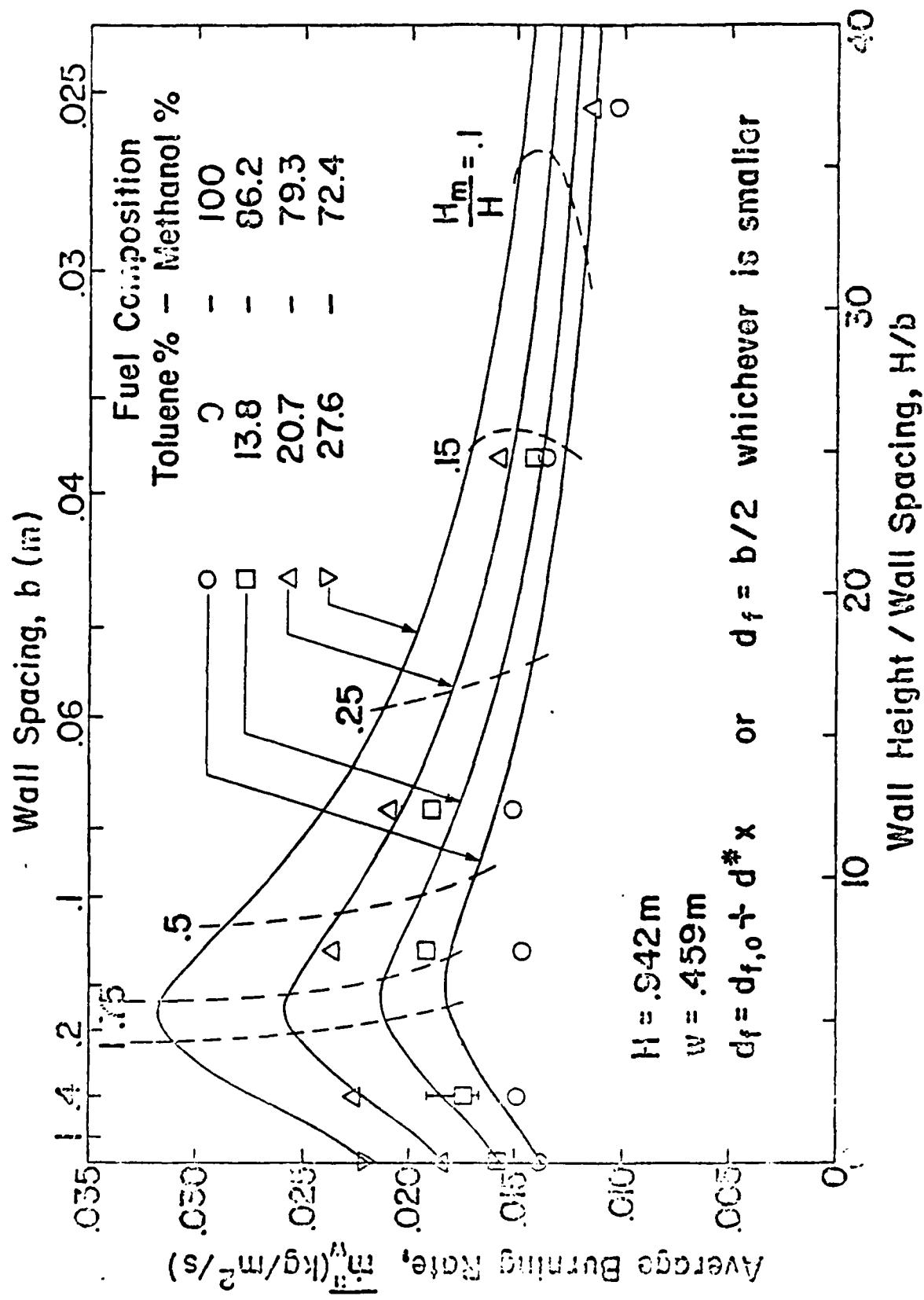


Figure 18: Effect of wall separation on the rate of burning of methanol and toluene-methanol mixtures along walls .942-m high. The solid lines represent the variation of the burning rate given by the yield-factor analysis.

FIGURE 10
Francesco Tamanini, "Calculations and Experiments on the Turbulent Burning of Vertical Walls in Single and Parallel Configurations," Factory Mutual Research 1979 - 3.

Building Separations (hazardous conditions)

Width of compartment (ft)	Per cent of window opening	Height of compartment (ft)					
		12.5	25	37.5	50	75	100
10	100	40	53.5	63	71	84	93.5
	75	35.5	47	55	61.5	72	79.5
	50	30	39	45	50	57.5	62.5
	25	22.5	28	32	34.5	37.5	39.5
20	100	53.5	73	87.5	100	119.5	135.5
	75	47	64	76.5	86.5	103	116.5
	50	39.5	53	62.5	71	83.5	93.5
	25	29	38	44.5	49.5	57	62
30	100	64	88	106	121.5	146	166.5
	75	56	76.5	92.5	105.5	126.5	143.5
	50	46	63	75.5	86	102.5	116
	25	33	45	53.5	60.5	71	78.5
60	100	86	120.5	147	169	203.5	235.5
	75	74	104.5	127.5	146.5	177.5	203.5
	50	60	85	104	119.5	144.5	165
	25	41	59.5	72.5	83	100.5	114
100	100	106	152	186.5	215.5	263	303
	75	90.5	131	161	186	227.5	261.5
	50	71.5	105.5	130	151	184.5	212.5
	25	46	71	89	103.5	127.5	146.5
200	100	136.5	204.5	255	297	366	423.5
	75	113.5	173.5	218	254.5	315	365
	50	85.5	136	173.5	203.5	253.5	294.5
	25	50	85	112.5	135	171	200.5

FIGURE 8
Building Separations (normal conditions)

Width of compartment (ft)	Per cent of window opening	Height of compartment (ft)					
		12.5	25	37.5	50	75	100
10	100	28	37	43	48	55.5	60.5
	75	24.5	32	37	41	46.5	50
	50	20.5	26	30	32.5	36	37.5
	25	15	18	20	20.5	21.5	22
20	100	37	51	60.5	69	81.5	91.5
	75	32.5	44	52.5	59	69.5	77.5
	50	27	36	42.5	47.5	55	60
	25	19	25	29	31.5	34.5	36.5
30	100	44	61	73.5	84	100.5	114
	75	33	53	63.5	72.5	86.5	97
	50	31	43	51.5	58.5	69	76.5
	25	21	29.5	35	39	44.5	48.5
60	100	58	83.5	102	117.5	142.5	163
	75	49.5	71.5	87.5	101	122.5	140
	50	39	57	70.5	81	98.5	118
	25	24.5	37.5	47	54	65	73
100	100	69.5	103.5	128	149	182.5	210.5
	75	58	88	109.5	127.5	158.5	180.5
	50	41	69	87	101.5	123.5	144.5
	25	26	42.5	55.5	66	82.5	95
200	100	83.5	134	171.5	201.5	251.5	292.5
	75	67	111	141	170.5	214.5	250
	50	48	83	110.5	132.5	169	198.5
	25	26.5	46.5	61.5	80.5	106.5	127

FIGURE 9
J. H. McGuire, "Fire and the Spatial Separation of Buildings," FIRE TECHNOLOGY,
Vol. 1 No. 4, November 1965, p. 279.

Figures 8 and 9 are taken from McGuire's study. They indicate that if the separation distance is as specified, it is reasonable to expect that flame spread will not take place.

Tamanini reports that parallel wall configurations appear to present a special burning phenomenon (15). For the "pure case" of parallel walls with equal height and width dimensions, the research shows that the burning rate seems to remain constant over a fairly wide range of wall spacings, and exhibit a behaviour that should be expected. This is illustrated by starting from the situation of walls infinitely far apart (started as the single wall limit), the burning rate first increases as the spacing is reduced, then drops. Therefore, there is a value of spacing for which the burning rate reaches a maximum.

The points in Figure 10 from the referenced study suggest that fuel production at low wall spacings is controlled by convective heat transfer, as indicated by the fact that burning rate measurements for different fuels tend to come closer to one another.

The study of radiation is limited to changes in the radiative heat flux to exposed surfaces and how this impacts on corresponding changes in burning rates. The resultant relationship shown in Figure 11 is also from the same study. This illustration appears to be important for constructing a more simplified relationship indexing the wall, height, and separation factors for exposure condition analysis.

15. Tamanini, Francesco. "Calculations and Experiments on the Turbulent Burning of Vertical Walls in Single and Parallel Configurations". Norwood (MA): Factory Mutual Research, 1979, p. 33.

SECTION V

Validation Studies

A. Overview

Phase I of this study identifies several important numerical changes that are in order for the original local assessment guide document, "A System for Local Assessment of the Conflagration Potential of Urban Areas". The suggested changes are incorporated into a new document, Local Assessment Guide for Conflagration Analysis: System II. Three separate validation studies were conducted using this document during the summer and fall of 1982. Results of this first validation study are reported below.

Phase II of this study was developed from the results and conclusions drawn from the first study phase. As reported in earlier sections, Phase II involved a second set of modifications to the individual block rating analysis and provides a new methodology for assessing fire spread between blocks. The validation of this work is also discussed below.

B. First Validation Process

The initial modification to the local assessment guide was first tested with a group of 32 fire protection engineering students at the University of Maryland. The validation process consisted of each student's completing a rating form for the sample block that is currently used in the study document using both the original methodology and the revised methodology. A comparative analysis was made of the ratings. Each student was also required to submit positive and negative comments on both approaches to the concept of

block rating analysis for conflagration determination. The main thrust of these remarks pertaining to both methods is as follows:

1. The fuel load parameter should incorporate a joint concept of fire growth and fire severity;
2. The method for evaluating structural walls is oversimplified. Each wall should receive an evaluation based on surface area, construction, and wall openings;
3. The method for evaluating roofs is oversimplified. The roof evaluation should also consider the roof covering and the roof supporting members; and
4. Buildings up to and including five stories should be evaluated according to individual story height and not combined into height groups.

The mathematical model was refined to accommodate these suggestions in accordance with quantitative factors determined from the literature search.

In the fall of 1982, a second validation study was conducted in the city of Alexandria, Virginia. A total of 17 persons participated in this exercise. Ten emergency management people representing the Council of Governments in the Washington area were combined with seven fire officers from Alexandria. The emergency management group was under the direction of Colonel Chapman while the fire department group was directed by Chief Charles W. Rule.

This group evaluated a structural block in the historic Old Town section of Alexandria using both the original methodology and the revised methodology. It was determined from interviews with both fire service and emergency management participants that such a comparative analysis was necessary. The basic objectives of the validation process were twofold:

1. to determine the perceived need and acceptance of the revised methodology and

2. to determine the consistency in computational results.

Each participant was given a copy of both methodologies two weeks in advance of the exercise. A sample block containing buildings was presented to the group and worked through on a chalkboard prior to introduction of the "real world" problem. The group visited the site and walked around the subject block.

Each person worked independently on the block rating analysis by both methods. Completion times ran from 3 1/2 to 5 hours; one person did not finish. Both oral and written comments were received on the exercise. The raters' numerical evaluations are presented in Figures 16 and 17.

C. Summary of the First Validation Process Findings

1. The original method is easier to comprehend and easier for computing the block rating.
2. The revised methodology is more applicable to evaluating mass fire potential in urban blocks during non wartime emergencies.
3. The change in fuel loading concepts is an important refinement to the revised methodology.
4. The individual wall analysis in the revised methodology is too complex, too time consuming, and needs to be simplified.
5. More up-front instruction is required before one starts to apply the methodology to a real world situation.
6. The time required to complete a block rating analysis by either method cannot be justified.

Figure 16

Summary Evaluation of the current Gage-Babcock Method of Conflagration Analysis

<u>Factor</u>	1-2 stories	Calculation Range		<u>Mean Value</u>
		<u>High</u>	<u>Low</u>	
1. Occupancy Load	18.0	17.27		17.5
2. Exterior Wall Construction	10.0	1.1		3.1
3. Floor Construction	10.0	7.86		8.1
7. Roof Construction	30.0	18.6		21.2
9. Height Distribution	62.5	14.0		36.9

<u>Factor</u>	3-5 stories		
1. Occupancy Load	18.5	18.2	
2. Exterior Wall Construction	14.2	0.0	
3. Floor Construction	10.0	0.0	
7. Roof Construction	30.0	22.32	
9. Height Distribution	37.5	16.0	

Summations: Column Totals			
Summation Rating	84.52	29.86	41.4
Density Multiplier	0.9	0.6	1.7
Terrain Multiplier	1.0	1.0	1.0
Final Block Rating	65.2	22.3	33.37

Standard Deviation for the Final Block Rating = 13.4

Figure 17

Summary Evaluation of the Revised Methodology for Mass Fire Block Analysis

<u>Factor</u>	1-2 Stories	Calculation Range		Mean Value
		High	Low	
1. Occupancy Load	18.0	17.27	17.5	
2. Exterior Wall Construction	21.0	5.6	7.8	
3. Floor Construction	10.0	7.86	8.1	
7. Roof Construction	37.2	12.9	33.6	
9. Height Distribution	NA	NA	NA	

<u>Factor</u>	3-5 stories		
1. Occupancy Load	18.5	18.2	18.3
2. Exterior Wall Construction	28.2	3.6	12.8
3. Floor Construction	10.0	0.0	8.8
7. Roof Construction	17.8	6.9	11.3
9. Height Distribution	NA	NA	NA

Summations: Column Totals			
Summation Rating	131.4	41.6	89.4
Density Multiplier	0.9	0.6	1.7
Terrain Multiplier	1.0	1.0	1.0
Final Block Rating	121.6	38.3	77.1

Standard Deviation for the Final Block Rating = 51.0

7. The methodology selected needs to be computerized.
8. The block rating analysis is probably of more importance to the fire service than to emergency management personnel.
9. This appears to be an important tool for city administrators in identifying high-fire-risk areas in the city.
10. A companion model is needed to measure fire spread potential between urban blocks.

D. Second Validation Process

The second round of validation studies had the mission of testing the methodology for both the local assessment process on mass fire development and fire spread between urban blocks. It is important to identify the functional objectives for the validation process. The following objectives can be evaluated both qualitatively and quantitatively.

1. Objective 1: To assess the clarity of the revised local assessment guide for each type of evaluation;
2. Objective 2: To determine if the revised local assessment guide can be accurately applied by local government personnel without external assistance;
3. Objective 3: To determine if local government personnel can apply the revised assessment guide to a given urban block or set of blocks and obtain essentially the same block rating; and
4. Objective 4: To determine if the validation participants considered the indexing system for measuring block rating impact and fire spread probability to be appropriate for the intended purpose.

To accomplish the overall mission of the project and to evaluate objective performance in applying the local assessment guides, an extensive validation process was conducted in each of three cities.

The selection of three cities for the program validation became a serious problem that significantly lengthened the study completion time. The study proposal suggested that the cities of Baltimore, Maryland; Chicago, Illinois; and Los Angeles, California be used for the validation process. After numerous contacts, meetings, and referrals, it became evident that none of these cities would cooperate in the study evaluation. There appear to be several reasons for this condition:

1. The large cities perceive that conflagration potential has been eliminated by urban renewal and rebuilding programs;
2. It was expected that the federal government would pay overtime for personnel involved in the exercise; and
3. The required information base concerning buildings, occupancies, and land use are not in place to conduct the exercise. Too much time would be required to complete this information prior to conducting the study.

Based upon the above conditions, it became necessary to obtain the cooperation and support of other cities. A total of nine additional cities were contacted before three agreed to participate in the validation exercise. The cities that participated in the validation program were Atlantic City, New Jersey; Louisville, Kentucky; and Syracuse, New York.

The validation process in those cities started in December, 1983, and concluded in March, 1984. The key elements of this process can be summarized as follows:

1. An initial site visit was made by the principal investigator to each of the cities. This visit was aimed at outlining the scope, method, and objectives of the validation study and obtaining a specified commitment to participate in the exercise. At this time one or more blocks were identified for the block rating analysis. Records and maps were checked to determine that the required information was in place or readily available for use by the participants. It was also requested that a person be identified as a responsible contact person to represent the respective cities and to coordinate the activities of local people. The person or persons so named are identified on page 61. In every case, the highest level of cooperation and involvement was demonstrated by the respective cities.

2. Each city was supplied with 15 copies of the local assessment guide for both the mass fire development model and the fire spread model between adjacent blocks.

3. Five teams of two persons each were to be named in each city. The team participants were instructed to read each of the local assessment guides and raise questions as necessary.

4. Each city was to complete the "A" form for the mass fire spread analysis on each building in the selected block and for buildings in the selected adjacent block.

5. Target dates were set for completing the actual validation study. These dates ranged from one month to three months. In some cases the dates were changed as many as three times because of local circumstances.

6. The validation exercise required two separate days in each of the validation cities.

7. An oral critique was held at the end of each validation program. Written comments were also obtained from most of the participants.

E. Summary of the Second Validation Process Findings

1. In one of the three cities, the "A" forms were nicely and accurately prepared without assistance. The principal investigator needed to assist two of the cities in completing the "A" forms.
2. Most of the questions concerning the "A" form revolved around interpretations for completeing wall calculations.
3. Two problems arose that were not adequately covered in the local assessment guide supplied to the cities -
 - a. The study methodology made no provision for fire communication by area ways and overhead connectors and
 - b. The fuel parameters for vacant buildings were not identified (there is still no agreement on this issue).
4. The basic data base for each block evaluation was made from existing Sanborn maps. However, between a half day and a full day of field work was required in each case to check on current structural and occupancy considerations.
5. A variety of problems occurred in the preparation of Form "B". These conditions can be summarized as follows:
 - a. Several of the participants needed a review in mathematical functions including methods for taking a percent of a number and then converting it back to a whole number.

- b. The concept of pro-rata analysis was especially bothersome to some participants as this concept related to categorizing buildings by height and area of the land cover.
 - c. Simple mathematical errors brought frustration to some of the participants.
 - d. In an few cases one member of the two-person team did a "lion's share" of the work. However, in most cases, the cooperative effort between participants was very good.
6. It can be concluded that the local assessment guide problem example was oversimplified from the actual blocks encountered. Participants did not know how to handle problems that were not addressed in the respective guides. Some intermediate ground rules were required during each exercise.
7. It was not possible to complete an individual block rating and a fire spread rating in the same day with any of the validation cities. The process is too time consuming even with the use of hand-held calculators.
8. The most severe problems developed during the completion of form "C". Under the methodology tested, it was necessary to first complete a form "B" for the exposed block. Then additional field work was required to check on wall faces, heights, areas, and wall openings. There was disagreement among the participants in making visual estimates on a percentage base. Further, the process could not continue in any of the validation cities without the direct intervention and assistance of the principal investigator. It can be concluded that the methodology is overly complex and requires too many hand calculations to be practical.

9. The level of agreement among participants in each of the named cities can be considered good. Figure 18 presents the block rating values according to each team by a substitute city letter designation for the city name. The anonymous designation was requested by each of the cities participating in the exercise. The following points are associated with the numerical evaluation presented in Figure 18.

- a. The level of agreement appears to be higher in the cities that were better prepared for the exercise by a thorough study of the local assessment guide;
- b. Teams that presented widely divergent block ratings appear to have had considerable difficulty with both the mathematics involved and the use of a calculator; and
- c. Agreement can be obtained on a given block by different raters using the same data base and calculation methods.

10. Each of the participants was asked to assign a numerical block value to the subject block in each respective city based on his or her professional judgement and the rating scale depicted on page 17 of the local assessment guide. The results of the perceived rating and the calculated rating are compared in Figure 19. An interpretative analysis of this information leads one to believe that there is no quantifiable reason for adjusting the benchmarks between classifications at this time.

F. Second Validation Process Observations

The study validation process conducted in Louisville, Kentucky; Atlantic City, New Jersey; and Syracuse, New York was well supported by each fire department. In each case the fire department administration appeared pleased

Figure 18

Calculated Block Rating Comparisons

Team	CITY		
	A	B	C
1	256.51	142.11	123.12
2	178.24	123.17	117.83
3	276.71	97.05	121.92
4	276.57	142.71	138.60
5	193.24	148.65	97.12
6	-	139.80	123.61
7	-	141.67	-
Mean	237.25	133.59	120.36
Standard Deviation	10.5	17.6	8.7

Figure 10

Difference Between Calculated Block Ratings and Perceived Block Ratings

CITY

Team	A		B		C	
	Calculated	Perceived	Calculated	Perceived	Calculated	Perceived
1	256	150	142	125	123	70
2	178	110	123	150	117	100
3	276	200	97	100	121	100
4	276	250	142	150	138	150
5	193	150	148	125	97	110
6	-	-	139	140	123	125
7	-	-	141	160	-	-

at the opportunity to participate in the validation exercise. The following individuals should be singled out for special recognition in coordinating the validation activities in each of the stated cities:

1. Louisville, Kentucky: Communications Superintendant Anthony Gray and Fire Prevention Sargent Osterritter.
2. Atlantic City, New Jersey: Chief John Brenner and Chief Speed.
3. Syracuse, New York: Timothy A. DeRuyscher, Fire Protection Engineer.

Observations based on the study validation process in each of the named cities can be divided into four areas for reflection. A discussion on each area follows:

1. Positive Considerations

- a. The local assessment guide for determining mass fire spread in urban areas and fire spread between urban blocks is an important new tool for risk management by fire department administrators.
- b. The structural risk assessment package is an important replacement for the structural grading recently deleted from the Insurance Services Office Fire Suppression Rating Schedule.
- c. There is a sense of agreement between the participating fire departments that the National Fire Academy should have responsibility for instruction on the correct and consistent use of the stated local assessment guides. The Executive Series programs on risk management appear to be a logical area for this program's implementation.
- d. The application of both local assessment guides appears advantageous for resource management in cities with population

2. The method of computing fire spread between block areas is excessively complex in the present form for the intended purpose of local assessment analysis.

Supplemental Statement: It was generally agreed among the study participants that the mechanism for determining the probability of fire spread is overly complex and theoretical for the purpose intended. The method simply does not appear to be practical for local government use. This observation is supported even if the methodology is computerized. There is strong support for the concept that only three variables are necessary for an approximate calculation:

1. The block rating of the exposure,
2. The block rating of the exposed block, and
3. A probability factor based on the gap width between blocks.

This suggested alternative to the study methodology has not been evaluated or tested.

3. The local assessment guide supplied to the three named validation cities does not provide sufficient depth and clarity for use by local government without further instruction and assistance in specific applications.

Supplemental Statement: The number of questions concerning use of the application guide and the degree of difficulty in applying the guide appears to be a direct function of participant preparation. In one of the validation cities the participants had obviously studied the guide in detail before the application exercise. The participants in this case exhibited only minor problems and the block ratings were quite uniform. The remaining two cities experienced more difficulty because the degree

large-scale disaster problem and the potential magnitude of that problem. Therefore, it follows that the assessment guide needs to be carefully considered for incorporation into the framework of the integrated emergency management system approach to emergency preparedness. This tool appears important to the evaluation process for considering crisis relocation requirements, communication needs, emergency direction and control, continuity of local government, resource management, and law and order in the event of a large scale fire problem.

B. Conclusions Relating to the Local Assessment Guide

The positive indicators listed above concerning the concepts, framework, and understandings associated with the revised local assessment guide are tempered by an identified list of concerns pertaining to the final phase of the stated study. The concluding concerns appear as follows:

1. The respective methods for computing individual block ratings and fire spread probabilities between urban blocks are labor intensive, requiring unjustifiable personnel times.

Supplemental Statement: It was the unanimous opinion of study participants that the actual calculation requirements should be programmed for suitable calculators or computerized. The program as it exists will not be well received by the fire service because of the time commitment required to perform necessary calculations. It further appears that the calculation program could be incorporated into fire department surveys and inspection programs. It was observed that the basic information required for block rating analysis is contained on the building information data forms currently used by many fire departments.

interested in the methodology set forth in this study as a means for evaluating large-scale risk conditions.

6. The assessment guide is appropriate for determining the relative structural risk potentials in a community on a quantitative base.

Supplemental Statement: Fire protection risk analysis is important to fire service administrators and municipal administrators. Fire officers are being educated on risk management at the National Fire Academy. Currently, the risk management course is concerned with the evaluation of single buildings or a small industrial complex; a methodology does not appear to be in place for examining large-scale fires, fires involving entire blocks or conflagration. The revised local assessment guide could be an important addition to the current method of fire risk analysis in the Executive Series of courses at the National Fire Academy.

It is currently understood that large-scale emergencies and community disasters require an integrated approach to the successful management of these events. This implies that the directors from a municipality or local government agency must become involved in both the planning and operation of large scale emergencies. At the community level this certainly involves fire, emergency management, police, highway, water supply, communications, building, health, utility, and relief agencies, and the clergy. The initial problem is to identify community threats before they become realities. The identification process must consider both the potential location for a large scale event and the predicted severity of that event.

The local assessment guide for mass fire potential and fire spread between urban blocks is an obvious tool for identifying one type of

rated under existing conditions. Alternative ratings can be computed on the basis of a change in variables. The comparison of these two ratings can demonstrate the potential benefits of change for a given set of conditions. The "before" and "after" evaluations can illustrate how an identified risk condition can be reduced.

5. The assessment guide is appropriate for determination of the relative risk assessments for structural conditions as an alternative to the disbanded community structural gradings previously provided by the Insurance Services Office.

Supplemental Statement: Prior to 1974, the Insurance Services Office Grading Schedule for Municipal Fire Protection (formerly the National Board of Fire Underwriters' Grading Schedule) contained an evaluation section relating to the structural conditions in a city. A city wide classification number on a scale of 1 to 10 provided the insurance industry with an evaluation of the structural risk level in relation to construction, occupancy, and fire spread characteristics. Individual blocks were also assessed for their individual conflagration potential although this evaluation was more of an engineering judgement than a quantitative analysis.

The structural evaluation process has been deleted in the current Fire Suppression Rating Schedule that replaced the earlier grading schedule. Fire officers in all three validation cities involved in this study perceived that the revised local assessment guide is an important replacement for the old structural gradings prepared by the insurance industry. It appears possible that the insurance industry might be

the fire problem. A number of different techniques have been used to identify the problem. Many of these techniques have been subjective in nature and non-quantifiable. The block rating method provides an intelligent alternative to current methods for identifying structural risk fire demand zones.

In this regard it is acknowledged that different risk levels require different complements of personnel and equipment to cope with the defined problem. The block rating concept could be important in establishing adaptive response criteria as a function of the perceived fire spread threat. Fire demand zone values are useful with fire station location models for analyzing the impact of alternative resource allocation plans.

Further, the numerical analysis provided by the block rating method provides an output indicator for educating the public on the potential threat of fire development in given blocks. Both urban administrators and citizens in the community can readily understand the simple indexing system. Beyond the area of fire protection, such information can be effectively used in community action programs.

4. The assessment guide is appropriate for determining the fire safety impact of urban renewal efforts through the assessment of "before" and "after" results of structural-occupancy changes.

Supplemental Statement: The merits of this item became recognized during the Phase II validation study. Senior fire officers from the Syracuse Fire Department indicated that the analysis of "before" and "after" affects of a block assessment could be extremely useful in evaluating the demolition or rehabilitation of buildings and/or occupancy changes as functions of area risks. In other words, city blocks can be

building may be reflected in computed insurance premiums or in needed fire flow. However, the only currently identified method for making this assessment at the block configuration level is the mass fire spread program discussed in this study. Computed block ratings can be used to compartmentalize selected blocks according to negligible, slight, moderate, or high probability of fire spread. These block ratings plotted on urban land use maps represent solid and concrete planning information for identifying potential community fire problem areas.

2. The assessment guide is appropriate for determining the relative probability of fire spread between urban blocks given a well developed fire in a single block.

Supplemental Statement: A second phase to the initial study was initiated in 1983 to develop a quantitative method for determining the probability of fire spread between urban blocks under the conditions of a well developed fire in the exposing block. The method discussed in this report develops a relative probability measure for making this assessment under several sets of assumed wind conditions. The complexity of the current analysis process dictates that further work is needed to provide local assessment programs with a more practical methodology. However, the basic concept of fire spread analysis is an important adjunct to the primary block rating analysis.

3. The assessment guide is appropriate for determining different quantitative indicators for fire demand zone identification.

Supplemental Statement: For the last decade, the American fire service has been interested in identifying areas of the community that required higher than normal complements of personnel and fire apparatus to handle

SECTION VII

Study Conclusions

A. Conclusions Relating to the Completed Study

The mission of this study to structure a local assessment guide for determining mass fire development potential in urban blocks and the probability of fire spread in urban blocks was well received and supported by all persons involved in the validation study. No one voiced or recorded any reason not to pursue and expand this program. Computed block ratings and fire spread probability ratings are viewed as important quantitative techniques for fire risk measurement in urban areas. In fact, a number of potential applications are identified for this local assessment process.

All of the study validation participants agreed in principle to the following proposition:

"The block rating concept for quantifying the mass fire spread potential in urban blocks and fire spread potential between urban blocks provides an important urban administration tool for community risk analysis."

Several application concepts are directly associated with this proposition.

1. The assessment guide is appropriate for determining the relative fire spread potential within selected urban structural block configurations.

Supplemental Statement: Not all buildings or configurations of buildings present the same level of risk from a developing fire. Conditions relating to building construction, occupancy factors, heights and areas, land density patterns, and terrain conditions are among the variables associated with risk differentials. The risk difference for a single

these values can be modified according to perceived wind conditions. This permits the evaluation of alternative spread conditions based on different degrees of wind speed.

R is the roof construction and cover value,
D is the construction density multiplier, and
N is the relative block rating value.

Formula computations are recorded on a worksheet according to building height categories. A summation process using the worksheet values leads to a final block rating figure. Final block ratings are related to an index chart to assess the relative risk of mass fire development in a single urban block. The tables, charts, and formula value indicators are presented in a companion document titled Local Assessment Guide for Conflagration Analysis: System II.

C. Fire Spread Between Blocks

A second method is used to evaluate the probability of fire spread between blocks. The developed analytic approach considered a group of relevant factors for the exposing block and a group of relevant factors for the exposed block. The factor sets are interrelated through a probability mechanism that accounts for the spread potential between two block faces.

These concepts are translated into the following quantitative expression:

Spread = Exposing Block X Street Width X Exposed Block
Index (RHV X WEV X WR) (Probability Value) (RHV X WEV) where:

RHV = Relative numerical hazard value for block

WEV = Wall Exposing Value

WR = Exposing wall ratios

SW = Street width probability (Table 9).

The formula relationship is systematically recorded on a separate worksheet. Again, a summary process is used to compute a final spread probability value. These values can be expressed on land use maps. Further,

SECTION VI

Local Assessment Guide

A. Introduction

The study reported in this paper is culminated in a program document titled Local Assessment Guide for Conflagration Analysis: System II. That document presents in detail the process for conducting a local assessment of mass fire potential in urban blocks and for determining the probability of fire spread between blocks in urban areas. All calculation materials including forms, charts, and tables are presented with the stated document. Study examples are given in the revised local assessment guide to illustrate the process for computing individual block ratings and fire spread ratings.

The final document incorporates technical changes recommended through the Phase II validation process. These changes include grammatical, explanatory, and other detailed revisions to the associated tables, charts, and figures. This final document does not reflect major conceptual changes to the rating methodology recommended by the validation process.

B. Block Rating Methodology

Individual block rating are determined by the systematic application of the following formula:

$$[(O + F + W) \cdot (H + R)] \cdot D = N \text{ where:}$$

O is the occupancy fuel load value,

F is the floor construction value,

W is the exterior wall construction value,

H is the height multiplier,

conflagration potential. No one questions the need for a tool to make a quantitative analysis of mass fire development in urban blocks and the probability of fire spread between blocks. The specific advantages of this assessment process and the implementation of the process does appear to differ among the cities involved with the validation exercises.

The concerns expressed in using the methodology can be satisfactorily resolved through the identified future development of a local assessment program to evaluate the potential for mass fire development and spread in urban areas. Any continuation and implementation of this work is dependent on a defined and supported future course of action.

number of fire service prevention personnel feel that the measurable impact of sprinkler protection on reducing the probability of large-scale fires could be the most valuable use of this tool.

d. Fire suppression people would like to see the addition of a methodology to evaluate the potential impact of given sets of fire service resources on halting or containing mass fires to the single blocks. In other words, the fire service envisions the use of the basic methodology to evaluate and adjust resource requirements to stop the spread of fires between blocks. However, the current methodology does not address this issue.

e. There appears to be considerable interest in correlating the block rating indices to needed fire flows as established by the Insurance Services Office.

f. An identified organization within the framework of the Federal Emergency Management Agency is needed to promote and monitor the local assessment program. Participants in the validation process strongly suggest that this program should be incorporated into the Executive Series at the National Fire Academy. This would appear to give the program the widest degree of exposure to the persons most likely to implement the program and to provide a methodology for incorporating total risk management concept into the integrated emergency management system.

G. Summary of the Validation Process

The validation exercises in combination strongly support the overall assessment process for local examination and charting of mass fire and

- e. There is an expressed concern that the insurance industry might use computed block ratings to increase premium charges or reduce earned credits under the Fire Suppression Rating Schedule.
3. Required Improvements
- a. Several concrete examples of various complexities need to be included with the local assessment guide.
 - b. The local methodology for assessing fire spread between urban blocks needs to be simplified if the computations are to be completed manually.
 - c. A section of the assessment guide should specifically discuss the collection and charting of information required to apply each local assessment guide.
 - d. There should be a glossary of terms used in the application guide.
 - e. All specialized terms and instructions need to be consistent throughout the written material.
4. Program Development
- a. The analytical process should be computerized for use by local government personnel. This would eliminate one of the major perceived obstacles to successful implementation of the local assessment process for mass fire and conflagration analysis.
 - b. The analysis process could be easily incorporated into the general building survey program already in place by many fire departments.
 - c. There appears to be a need for assessing the impact of automatic sprinkler protection in the mass fire spread model. A

ranges from 50,000 to 500,000 due to the remaining core of central business districts containing large groupings of frame and brick wood-joisted (ordinary) construction.

- e. Computed block ratings and fire spread ratings can be effectively used to educate both urban administrations and local citizens on potential large-scale problems within a city.
- f. The potential for large-scale fire events may signal the need to integrate the planning function for these events with other community agencies. In essence, this provides a baseline calculation for initiating an integrated emergency management system to cope with potential disasters caused by mass fire development and fire spread between urban blocks.

2. Concerns

- a. Municipalities need instruction and guidance in the proper selection and application of the two local assessment guides.
- b. The calculation process for individual block ratings and fire spread ratings between blocks are time consuming.
- c. The present methodology for assessing potential fire spread between urban blocks is too complex for practical application.
- d. All three cities participating in the validation program expressed a concern over the possible misinterpretation of the block rating values by agencies of local government dealing with economic development; it may be difficult to promote economic development in high-risk areas.

of participation was minimal and a number of individuals could not effectively or consistently apply the basic mathematical operations required to work through the problems without assistance.

The local assessment guide does not specify procedures for all possible circumstances. Some participants had problems when a condition -- such as a vacant building -- occurred that was not identified in one of the calculation tables. Others simply exhibited difficulty in transposing the concepts and information from the sample calculation the assessment guide to a real world situation. Several individuals suggested that more sample blocks be included in the guide for reference and review.

4. The local assessment guide under consideration probably will not be accepted by the fire service without a supporting educational program.

Supplemental Statement: Most of the study participants favor an educational program that will establish the scopes and objectives of the program in addition to working through sample problems with appropriate instruction. This concept appears to be more acceptable than providing a voluminous document of far-reaching detail.

In accordance with Part A of this section, it appears appropriate to develop this program in conjunction with courses at the National Fire Academy. A logical place for course implementation would be in conjunction with risk analysis programs.

5. A number of fire officers, especially in fire prevention bureaus, would like to see an adjustment made to the methodology that would account for buildings protected by automatic sprinkler systems.

Supplemental Statement: A strong concern was expressed by some participants that the risk model does not consider the intervention of automatic sprinkler protection for the control of developing fires in urban blocks. As noted, the current concept is to treat buildings as being "unprotected". In light of the strong emphasis to transfer some urban fire protection responsibilities from the public sector to the private sector, it is strongly suggested that the assessment method consider the impact of internal protection as a function of altering the block rating value. Such an evaluation could be important in improving the quality of life and the reduction of risk in urban areas.

6. A number of fire officers suggested that impact measures be developed for assessing the value of the responsible fire department and other local government agencies in halting a spreading fire between structural blocks.

Supplemental Statement: The concern reflected in this conclusion follows in concert with the previous item. The value of fire protection in reducing the fire spread probability measure needs to be accounted for in the study. Again, this additional tool would give urban administrators still another mechanism for studying alternative arrangements to a defined problem.

C. Summary

It can be summarized that the general scope, methods, and objectives of the revised local assessment guide for determining mass fire spread potential in urban blocks and the probability of fire spread between blocks is fundamentally sound and needs to be advanced to the fire service. The

completed work of this study still needs expansion and refinement to accomplish this objective. The final study section addresses concepts for future work.

SECTION VIII

Future Work

The successful use and implementation of the local assessment guide into the mainstream of urban affairs is dependent upon the support and program promotion of the total program by a division of the Federal Emergency Management Agency. Participants involved in the study's Phase II validation process indicate that risk assessment programs for determining mass fire development in urban blocks and the probability of fire spread between blocks can best be accomplished through one or more programs at the National Fire Academy. Any future work concerning this program is dependent of the assignment of responsibility to a sponsoring organization.

It appears that a major problem with the original Gage-Babcock conflagration methodology and the revised methodology for developing block ratings revolves around the very time-consuming process of computing block values. The continuation of a manual approach to the analysis process will probably result in a low degree of program acceptance. The time commitments to carry forth computations simply cannot be justified at the local government level. One or more computer programs or calculator programs need to be developed for each analysis portion of the study. The completed software packages could be provided as a companion resource to the local assessment guide.

There is a strong interest among the study validation participants to develop a method for assessing the potential impact of automatic sprinkler protection on reducing block rating values. An automatic sprinkler assessment program could serve as an important adjunct to the total risk assessment of

urban blocks under fire spread characteristics. The preparation of such a program should be carefully considered.

There is a companion interest among the study participants to develop a method for assessing the potential impact of fire department operations on preventing or reducing fire spread between urban blocks. This topic should be of considerable interest to the fire service in risk assessment evaluations. A methodology to evaluate fire department operations in confining and controlling structural fires to the block of origin should also be carefully considered.

It appears that the methodology for computing the probability of fire spread between urban blocks is overly complex. It should be recognized that all final calculations using the described methodology are relative. Therefore, it appears possible to reduce the impact measures to a basic consideration of the differences in exposing block rating values plus a probability value based on the gap width between block faces. The rating scale will probably require adjustment based on the model simplification. The revision process needs to be undertaken as future work.

The above concepts for future work on this project should significantly improve the utility of the local assessment guide.

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